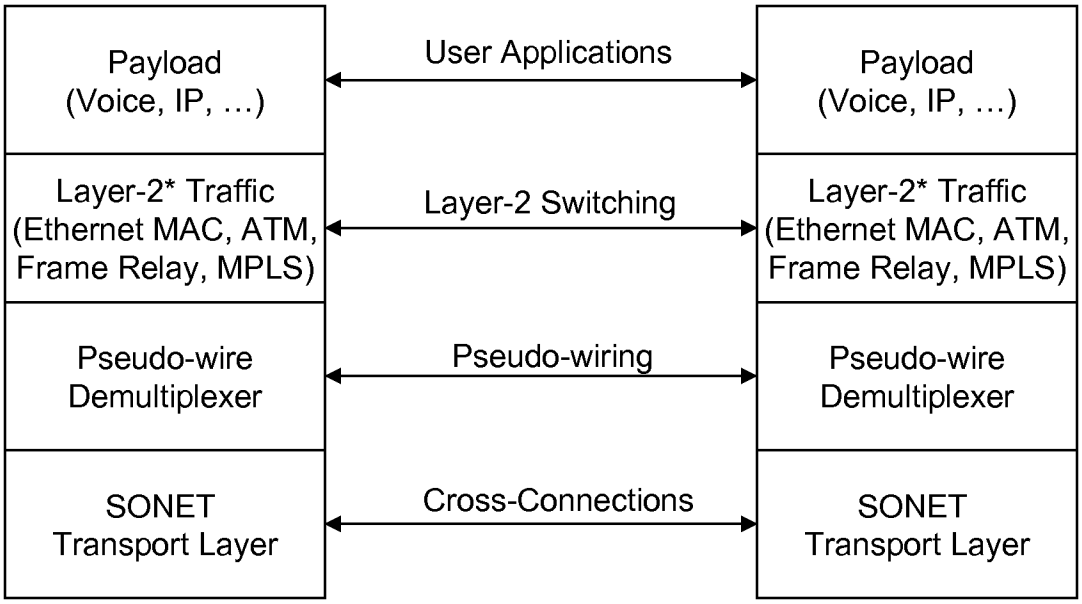


Figure 1

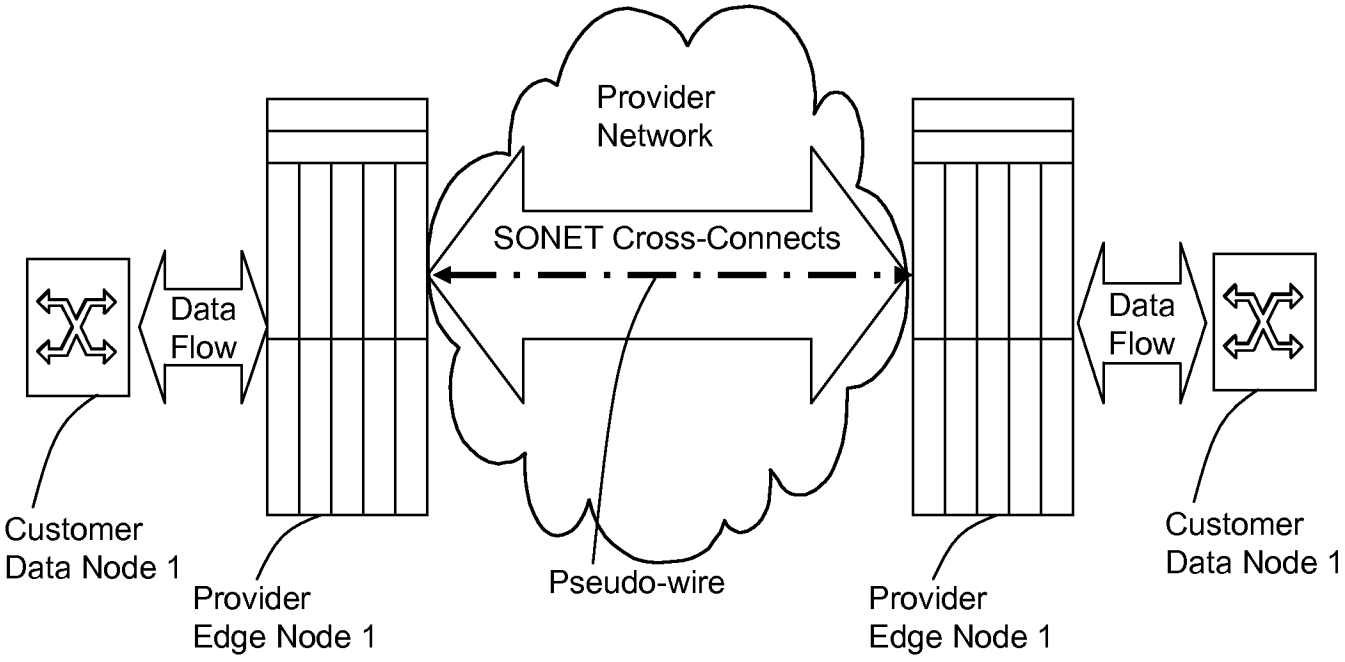


Figure 2

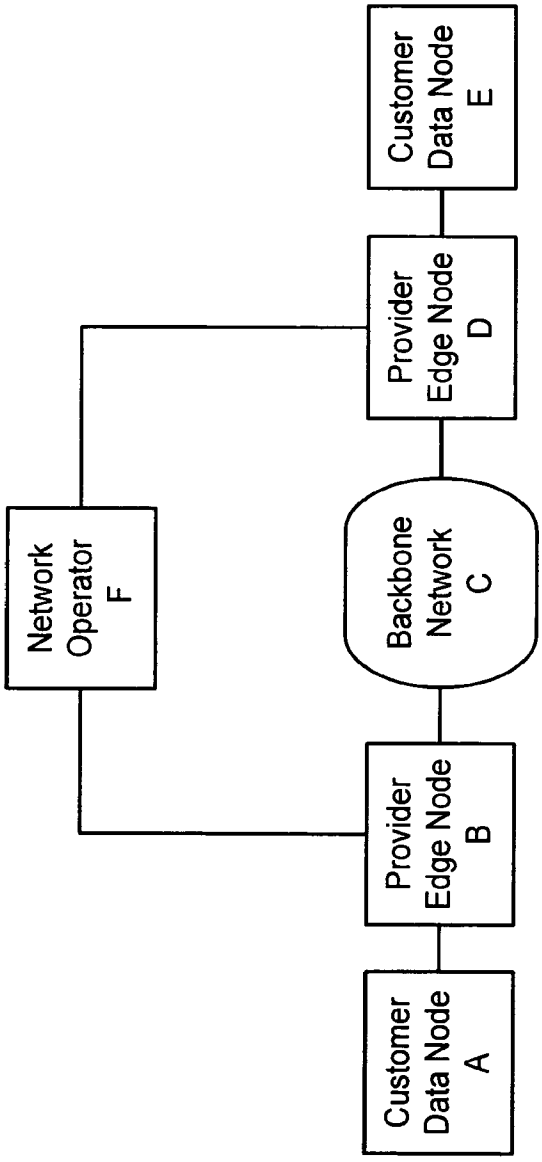

Customer Data Node A
Provider Edge Node B
Backbone Network C
Provider Edge Node D
Customer Data Node E
Network Operator F

Figure 3

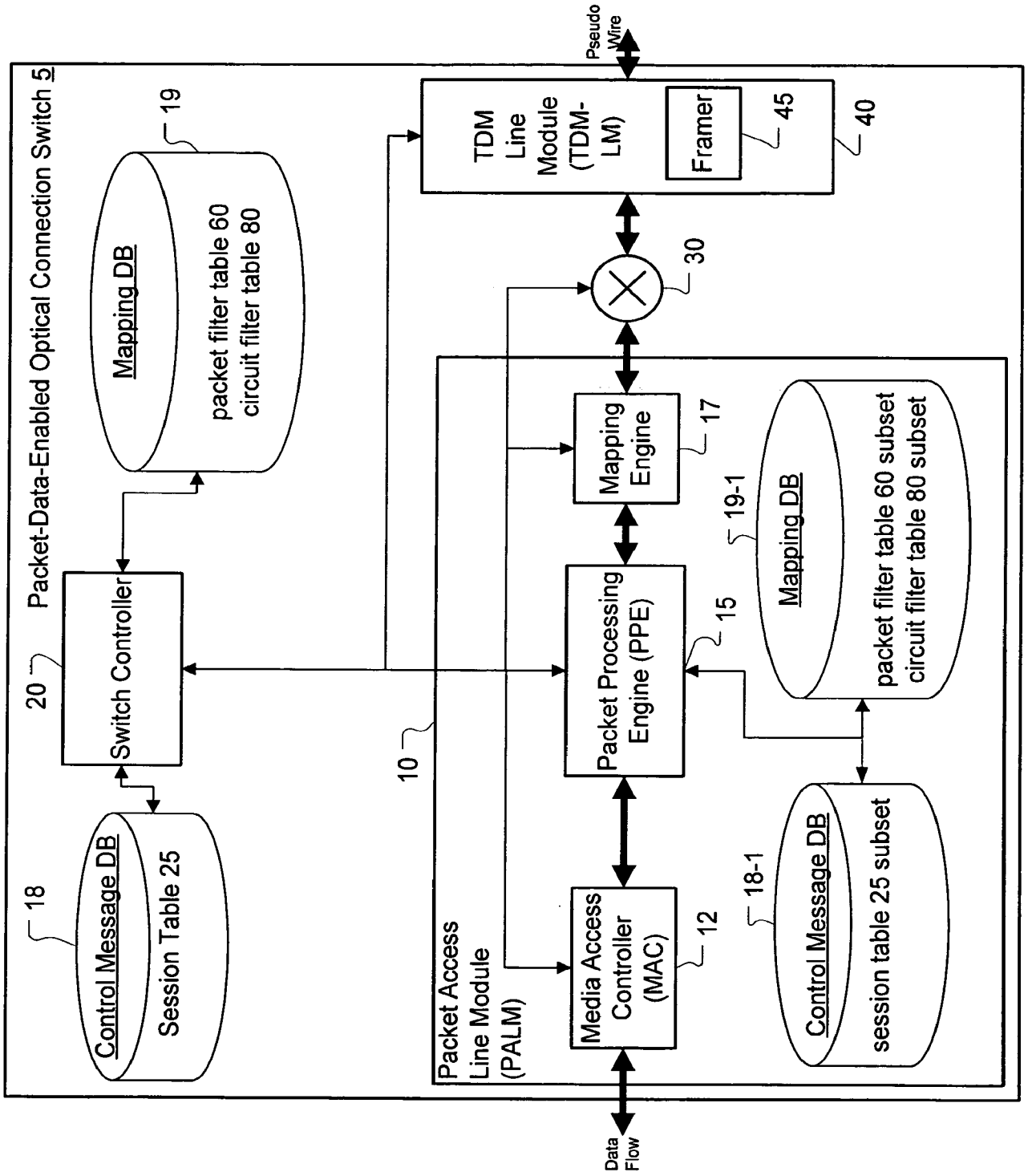

Packet-Data-Enabled Optical Connection Switch 5
Pseudo Wire
TDM Line Module (TDM-LM)
Framer
45
40
30
19
Mapping DB
packet filter table 60
circuit filter table 80
Switch Controller
20
Mapping Engine
17
19-1
Mapping DB
packet filter table 60 subset
circuit filter table 80 subset
10
Packet Processing Engine (PPE)
15
18
Control Message DB
Session Table 25
Packet Access Line Module (PALM)
Media Access Controller (MAC)
12
18-1
Control Message DB
session table 25 subset
Data Flow

Figure 4

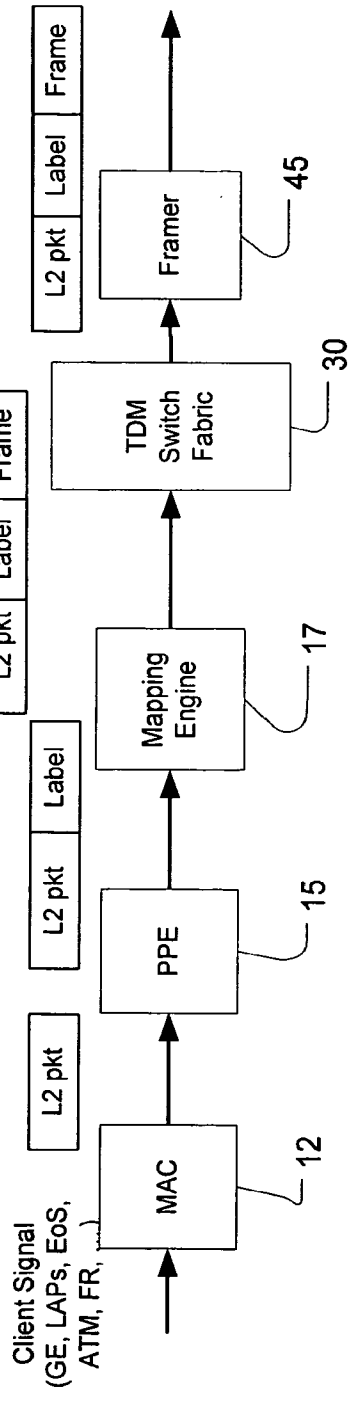


Figure 5

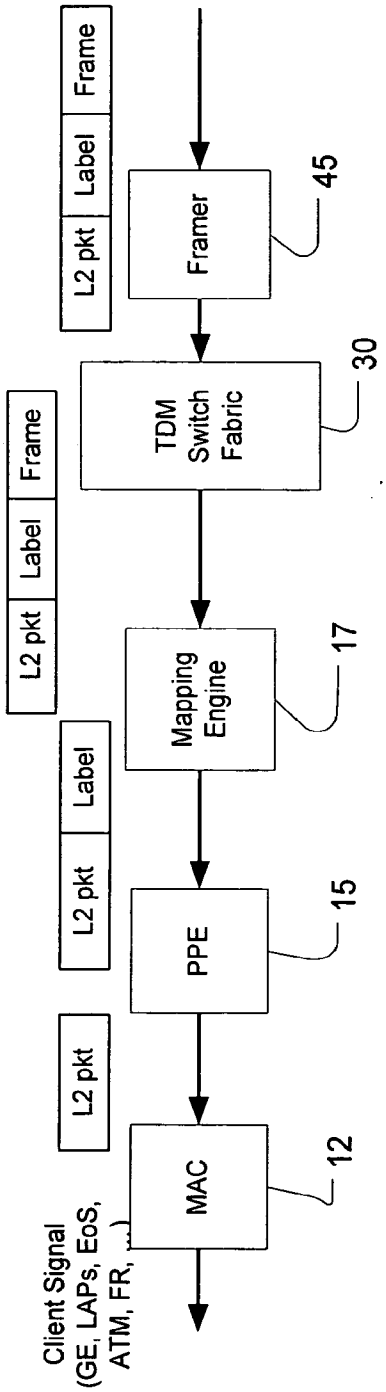


Figure 6

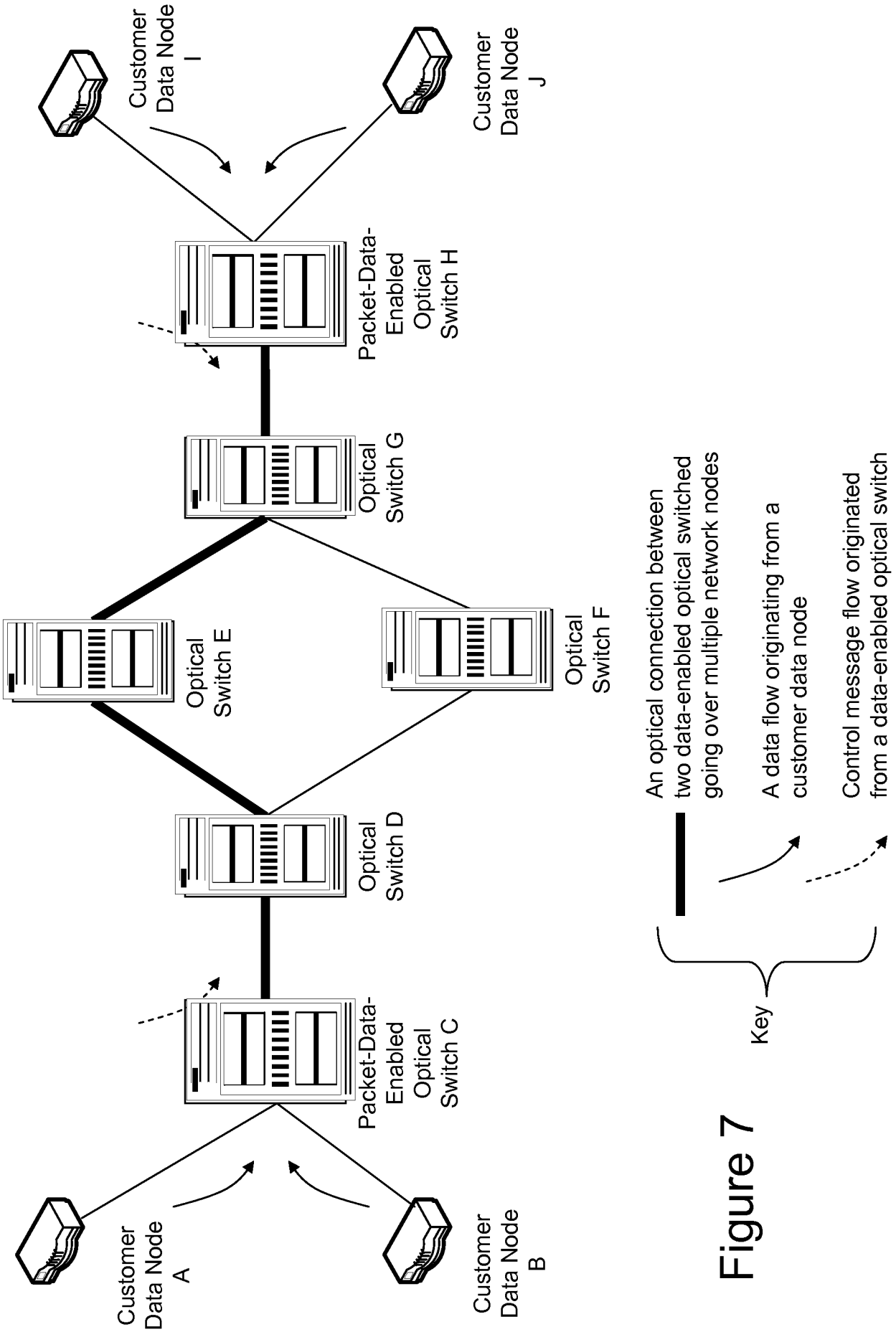

Customer Data Node I
Customer Data Node J
Packet-Data-Enabled Optical Switch H
Optical Switch G
Optical Switch E
Optical Switch F
Optical Switch D
Packet-Data-Enabled Optical Switch C
Customer Data Node A
Customer Data Node B
An optical connection between two data-enabled optical switched going over multiple network nodes
A data flow originating from a customer data node
Control message flow originated from a data-enabled optical switch
Key

Figure 7

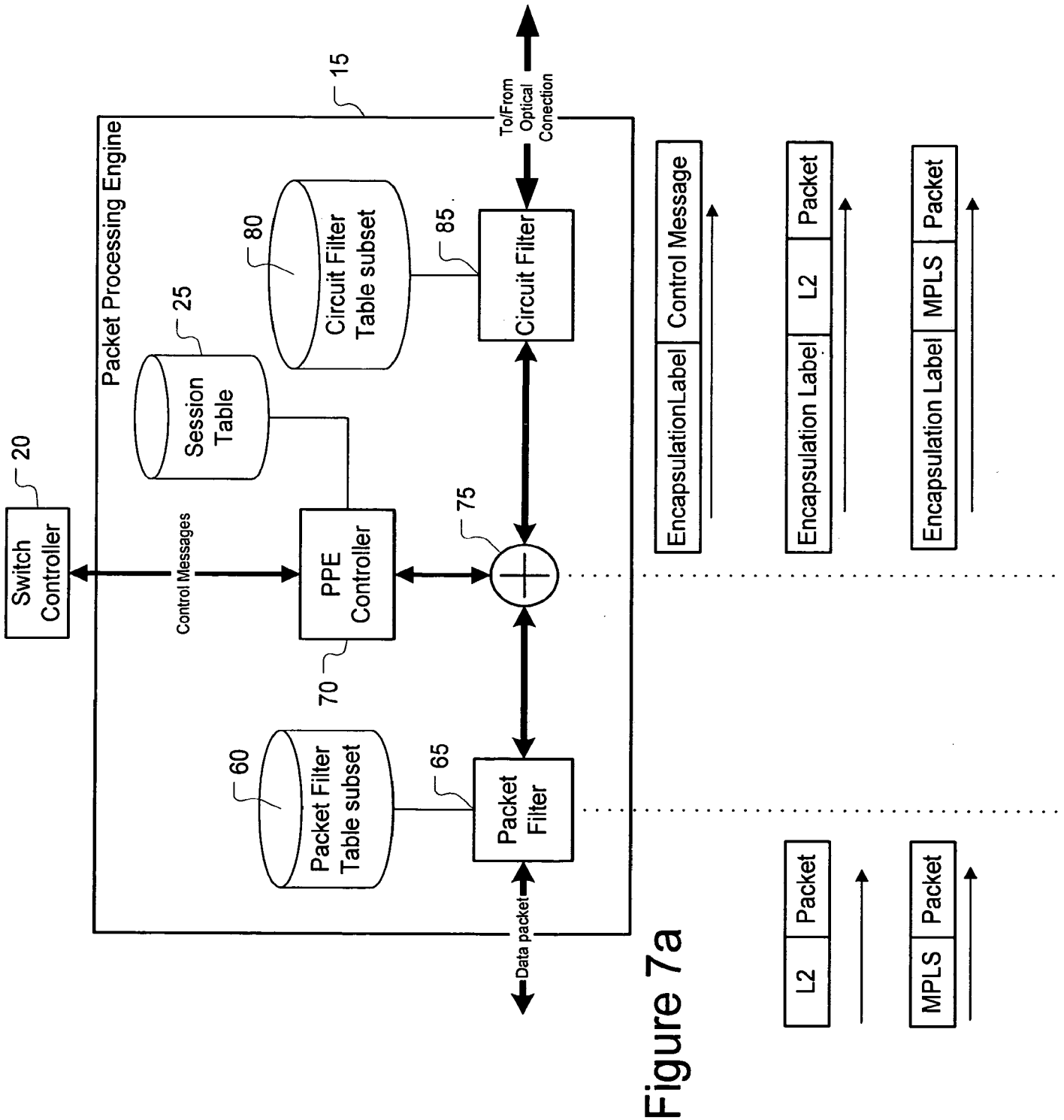

Packet Processing Engine
15
To/From Optical Conection
Switch Controller
20
Control Messages
PPE Controller
70
Session Table
25
Circuit Filter Table subset
80
Circuit Filter
85
75
Packet Filter Table subset
60
Packet Filter
65
Data packet
EncapsulationLabel
Control Message
Encapsulation Label
L2
Packet
Encapsulation Label
MPLS
Packet
L2
Packet
MPLS
Packet

Figure 7a

REPLACEMENT SHEET

60

PACKET FILTER TABLE				
PACKET FILTER (DATA INTERFACE, LABEL)	OUTGOING OPTICAL CONNECTION	ENCAPSULATION LABEL	FILTER PRIORITY	GUARANTEED QOS
PACKET FILTER-1 (PORT 1, ETHERNET VLAN 100)	SONET VCG NUMBER 3	MPLS LABEL 10000	3	X
PACKET FILTER-2 (PORT 5, ATM VCI/VPI 12/45)	SONET VCG NUMBER 3	MPLS LABEL 20000	3	Y
PACKET FILTER-3 (PORT 2, FR DLCI 900)	OPTICAL INTERFACE 1	MPLS LABEL 500	3	Z
PACKET FILTER-4 (PORT 1, MPLS LABEL 10000)	SONET VCG NUMBER 5	MPLS LABEL 10001	1	S

Figure 7b

REPLACEMENT SHEET

80

CIRCUIT FILTER TABLE			
CIRCUIT FILTER (OPTICAL CONNECTION, LABEL)	OUTGOING DATA INTERFACE	OVERWRITTEN LABEL	GUARANTEED QOS
CIRCUIT FILTER-1 (SONET VCG 3, LABEL 20000)	DATA PORT 1	ETHERNET VLAN 200	X
CIRCUIT FILTER-2 (SONET VCG 3, LABEL 20001)	DATA PORT 2	ATM VCI/VPI 23/56	Y
CIRCUIT FILTER-3 (OPTICAL INTERFACE 1, LABEL 300)	DATA PORT 1	NONE	Z
CIRCUIT FILTER-4 (SONET VCG 5, LABEL 12000)	DATA PORT 23	FRAME RELAY DLCI 200	S
CIRCUIT FILTER-5 (SONET VCG 3, LABEL 3)	HOST INTERFACE	NONE	T

Figure 7c

REPLACEMENT SHEET

25

SESSION TABLE			
SESSION (CONTROL MESSAGE ID)	OUTGOING OPTICAL CONNECTION	ENCAPSULATION LABEL	GUARANTEED QOS
SESSION 1 (TCP SRC PORT 1345)	SONET VCG NUMBER 3	MPLS LABEL 3	X
SESSION 2 (TCP SRC PORT 3456)	SONET VCG NUMBER 3	MPLS LABEL 3	Y
SESSION 3 (UDP PORT 1998)	OPTICAL INTERFACE 1	MPLS LABEL 10000	Z

Figure 7d

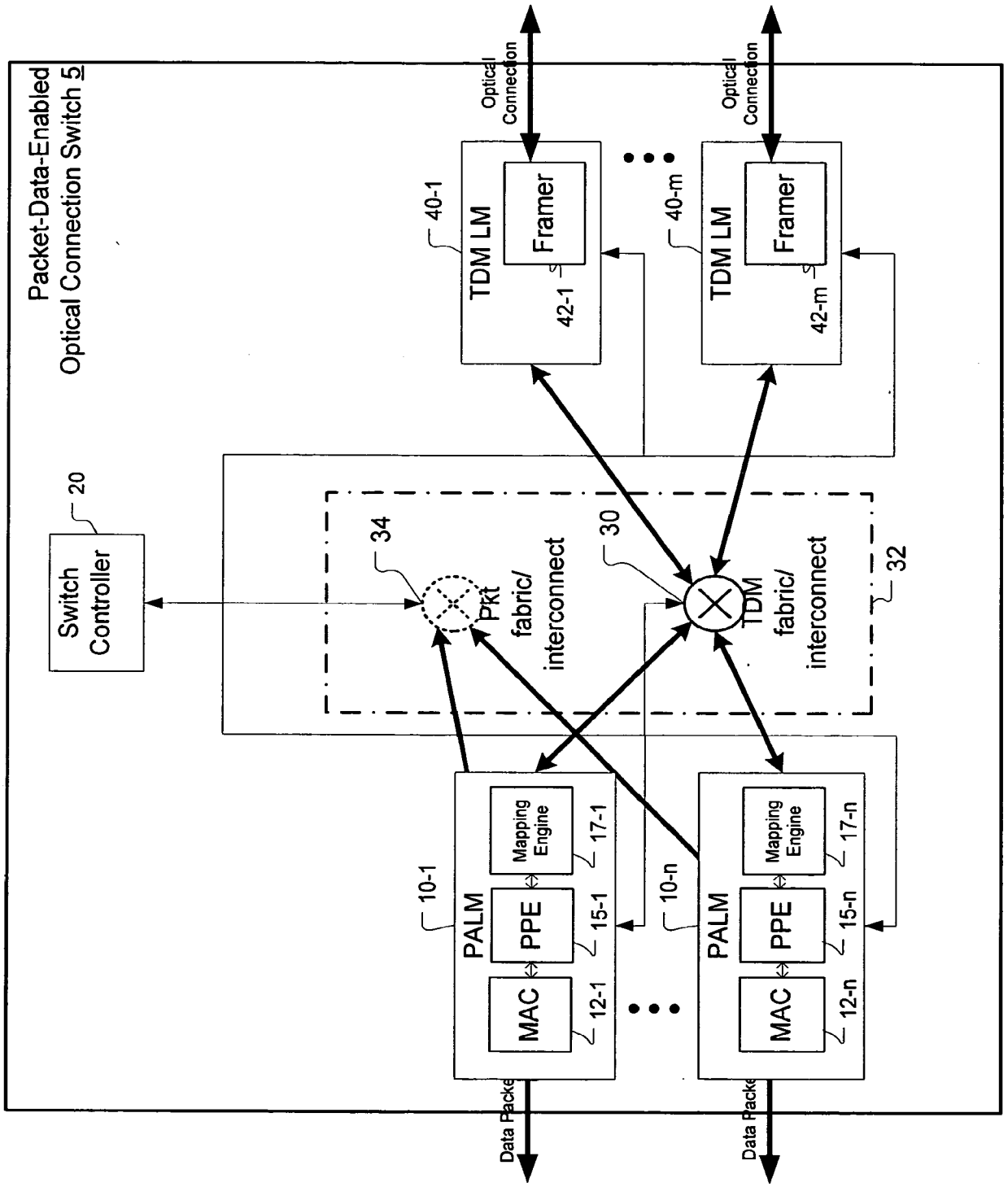

Packet-Data-Enabled
Optical Connection Switch 5
Switch Controller
20
34
Pkt fabric/ interconnect
30
TDM fabric/ interconnect
32
Optical Connection
Optical Connection
40-1
TDM LM
Framer
42-1
40-m
TDM LM
Framer
42-m
10-1
PALM
MAC
12-1
PPE
15-1
Mapping Engine
17-1
10-n
PALM
MAC
12-n
PPE
15-n
Mapping Engine
17-n
Data Packe
Data Packe

Figure 8

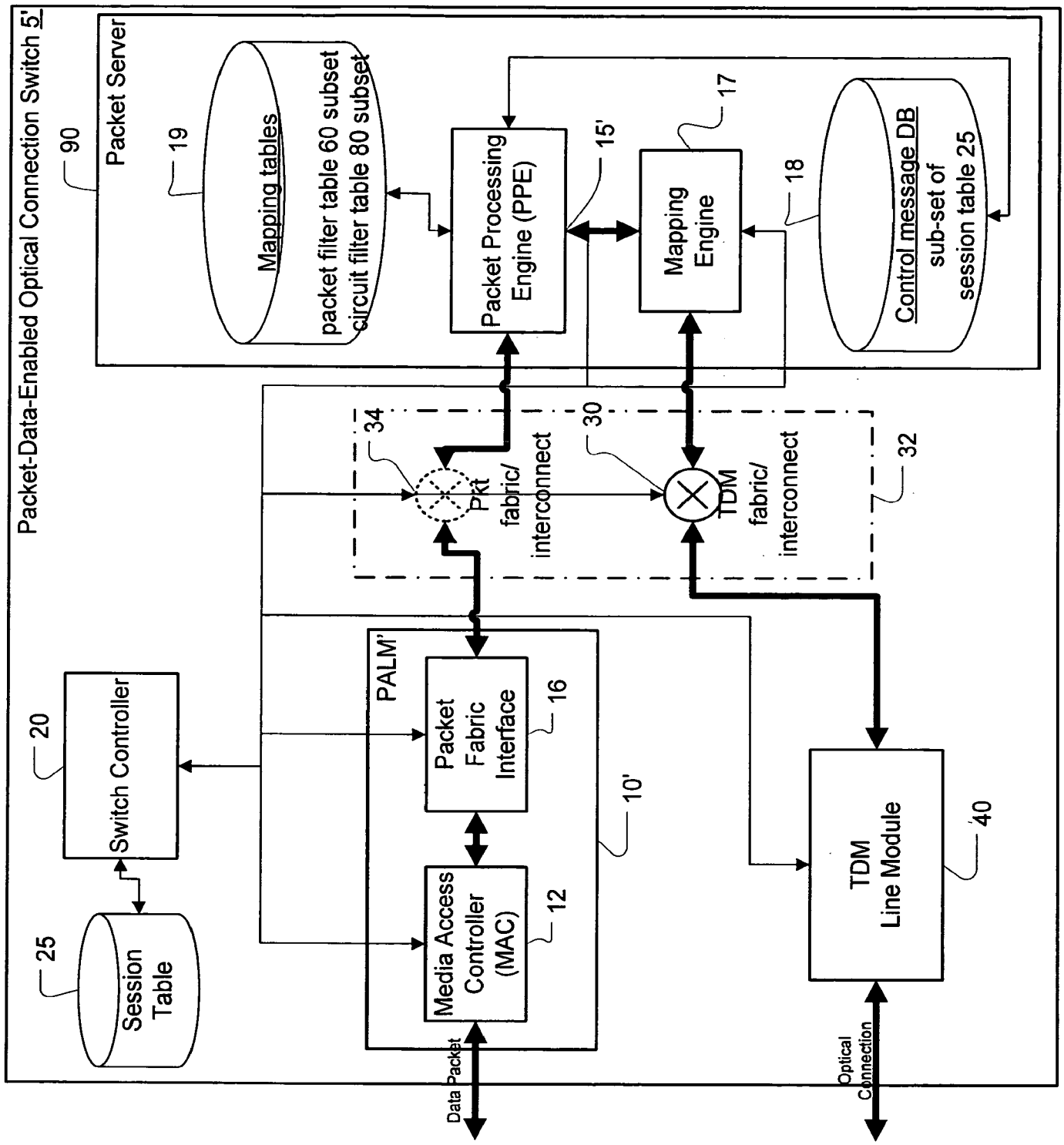

Packet-Data-Enabled Optical Connection Switch 5'
90
Packet Server
19
Mapping tables
packet filter table 60 subset
circuit filter table 80 subset
Packet Processing Engine (PPE)
15'
Mapping Engine
17
18
Control message DB
sub-set of session table 25
34
Pkt fabric/ interconnect
30
TDM fabric/ interconnect
32
PALM'
Packet Fabric Interface
16
Media Access Controller (MAC)
12
10'
Switch Controller
20
25
Session Table
TDM Line Module
40
Data Packet
Optical Connection

Figure 9

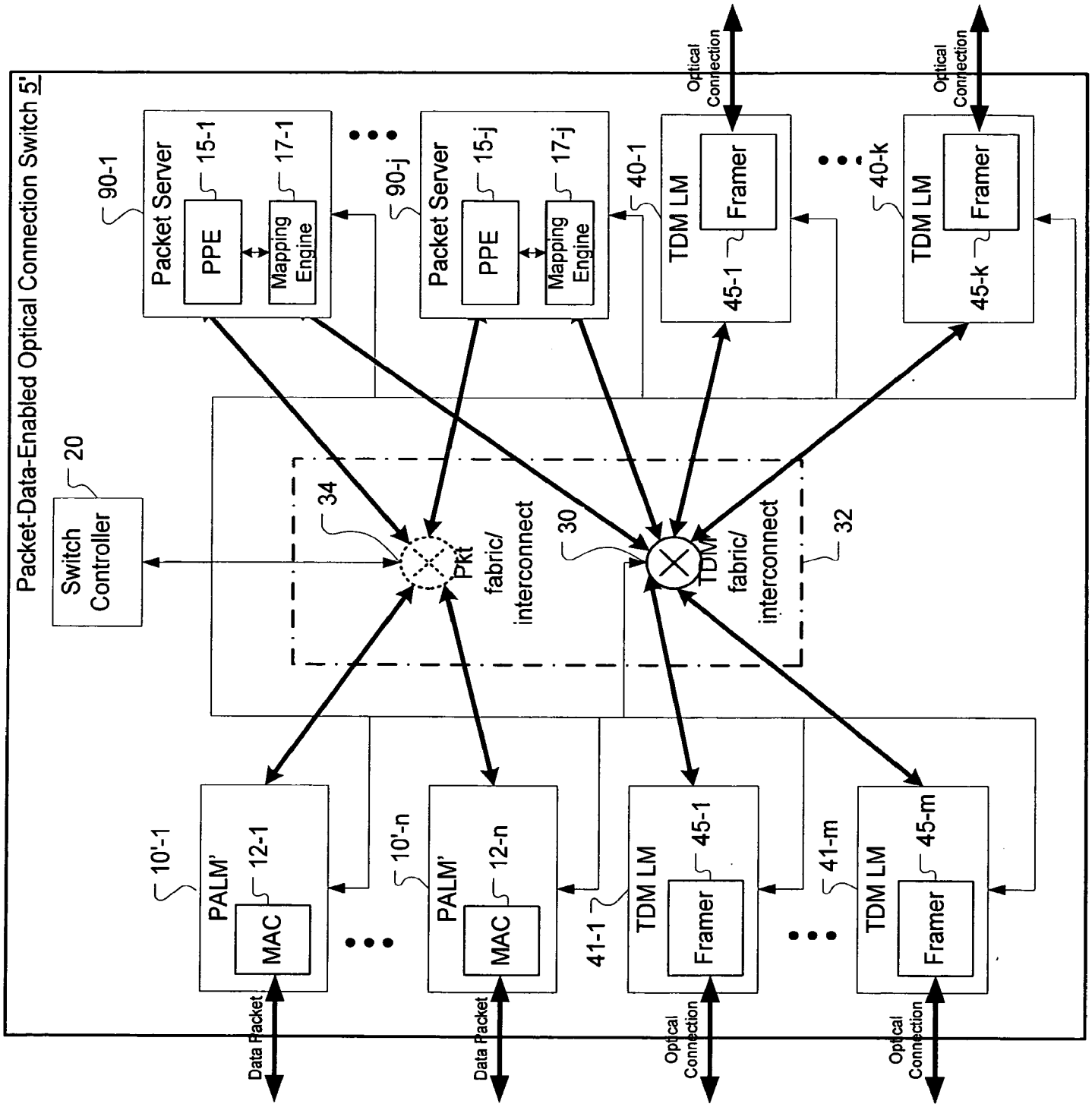

Packet-Data-Enabled Optical Connection Switch 5'
Switch Controller
20
Packet Server
PPE
Mapping Engine
15-1
17-1
90-1
Packet Server
15-j
17-j
90-j
TDM LM
Framer
45-1
40-1
TDM LM
Framer
45-k
40-k
Optical Connection
Optical Connection
34
Pkt fabric/ interconnect
30
TDM fabric/ interconnect
32
PALM'
MAC
12-1
10'-1
PALM'
MAC
12-n
10'-n
TDM LM
Framer
45-1
41-1
TDM LM
Framer
45-m
41-m
Data Packet
Data Packet
Optical Connection
Optical Connection

Figure 10

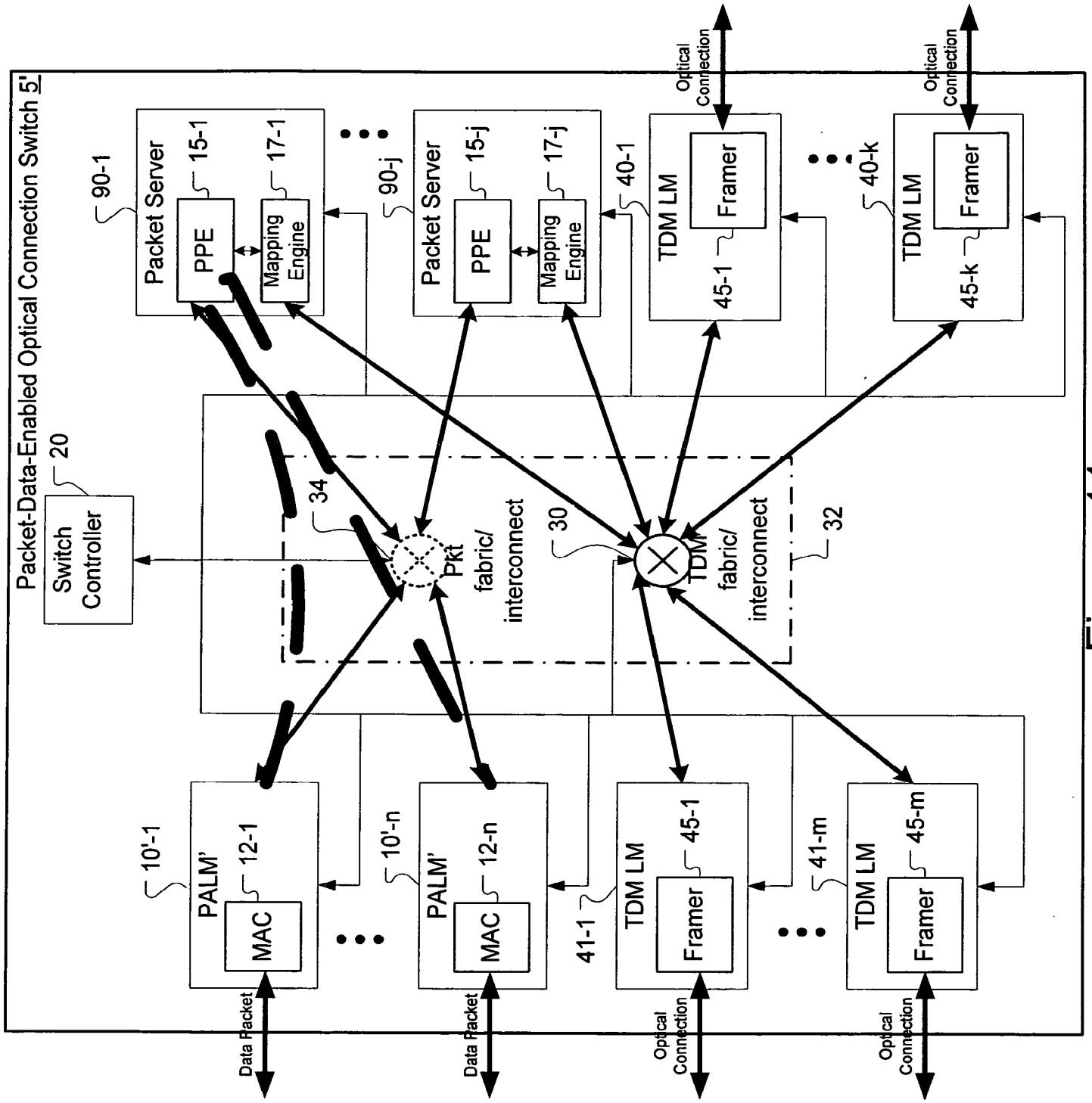

Packet-Data-Enabled Optical Connection Switch 5'
Switch Controller
20
34
Pkt fabric/ interconnect
30
TDM fabric/ interconnect
32
90-1
Packet Server
PPE
15-1
Mapping Engine
17-1
90-j
Packet Server
PPE
15-j
Mapping Engine
17-j
40-1
TDM LM
Framer
45-1
40-k
TDM LM
Framer
45-k
Optical Connection
Optical Connection
10'-1
PALM'
MAC
12-1
10'-n
PALM'
MAC
12-n
41-1
TDM LM
Framer
45-1
41-m
TDM LM
Framer
45-m
Data Packet
Data Packet
Optical Connection
Optical Connection

Figure 11

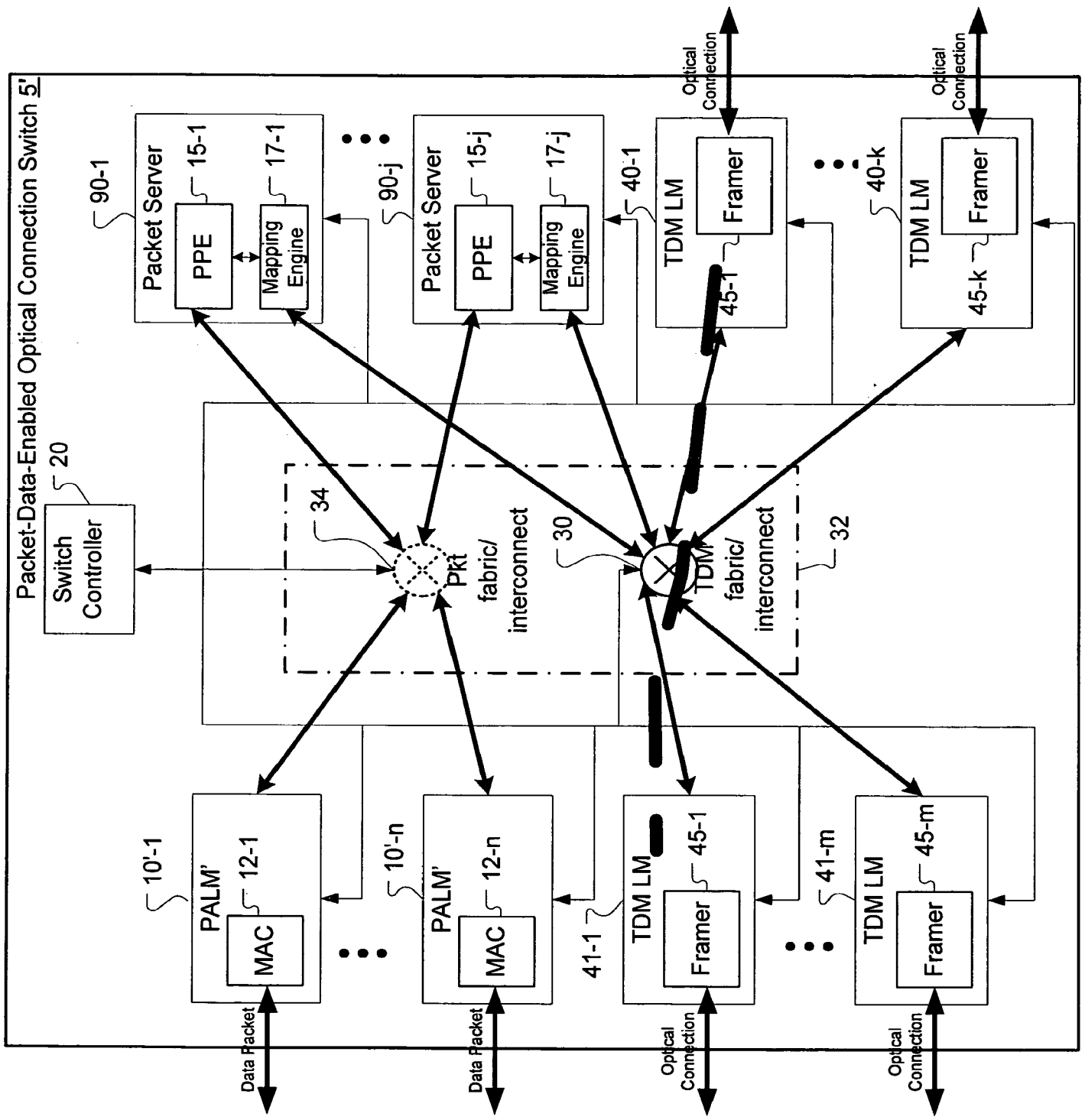

Packet-Data-Enabled Optical Connection Switch 5'
Switch Controller
20
34
Pkt fabric/ interconnect
30
TDM fabric/ interconnect
32
90-1
Packet Server
PPE
15-1
Mapping Engine
17-1
90-j
Packet Server
PPE
15-j
Mapping Engine
17-j
40-1
TDM LM
Framer
45-1
40-k
TDM LM
Framer
45-k
Optical Connection
Optical Connection
10'-1
PALM'
MAC
12-1
10'-n
PALM'
MAC
12-n
41-1
TDM LM
Framer
45-1
41-m
TDM LM
Framer
45-m
Data Packet
Data Packet
Optical Connection
Optical Connection

Figure 12

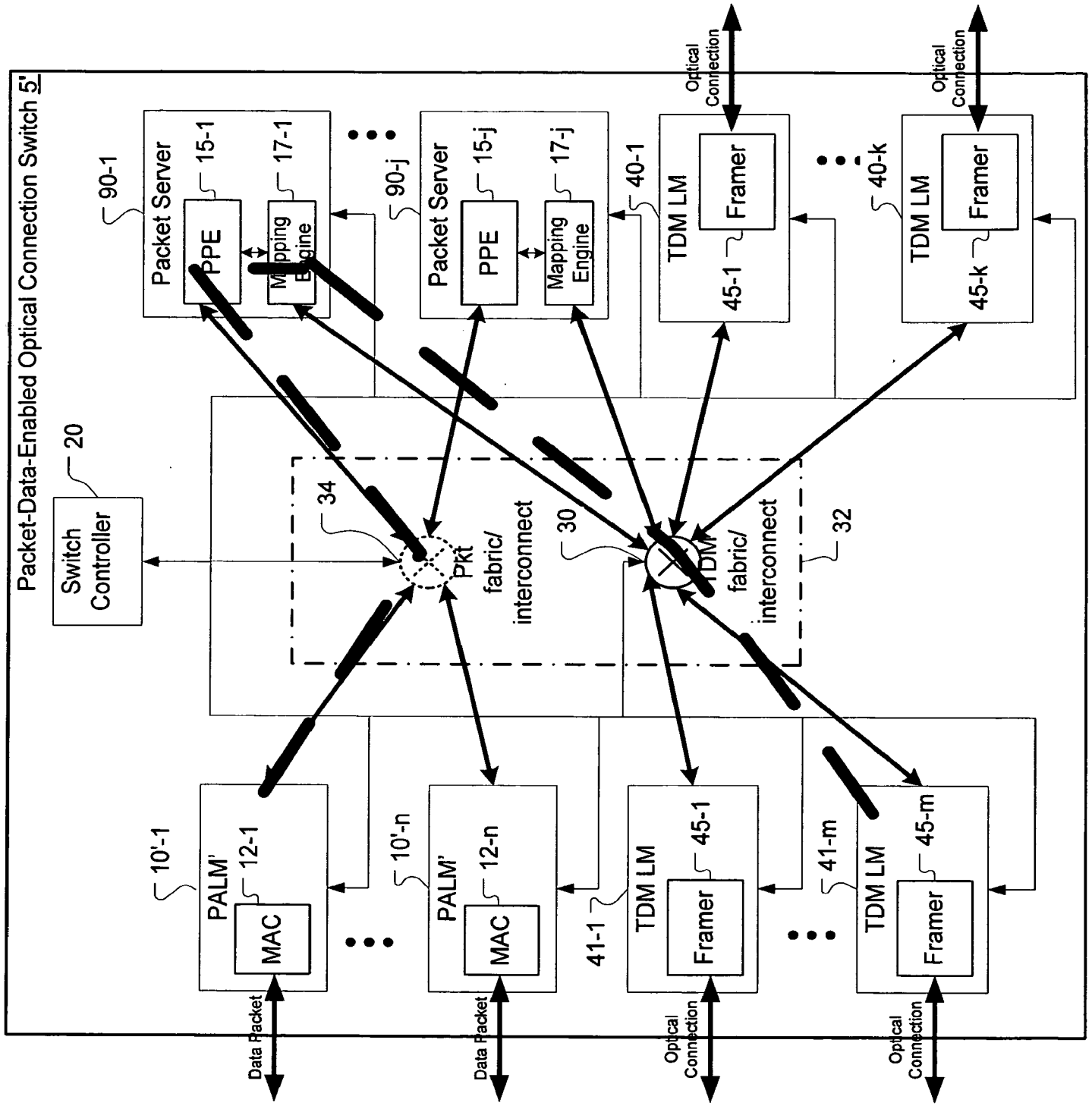

Packet-Data-Enabled Optical Connection Switch 5'
Switch Controller
20
Packet Server
PPE
Mapping Engine
15-1
17-1
90-1
90-j
15-j
17-j
40-1
40-k
TDM LM
Framer
45-1
45-k
Optical Connection
34
Pkt fabric/ interconnect
30
TDM fabric/ interconnect
32
PALM'
MAC
12-1
12-n
10'-1
10'-n
41-1
41-m
45-m
Data Packet

Figure 13

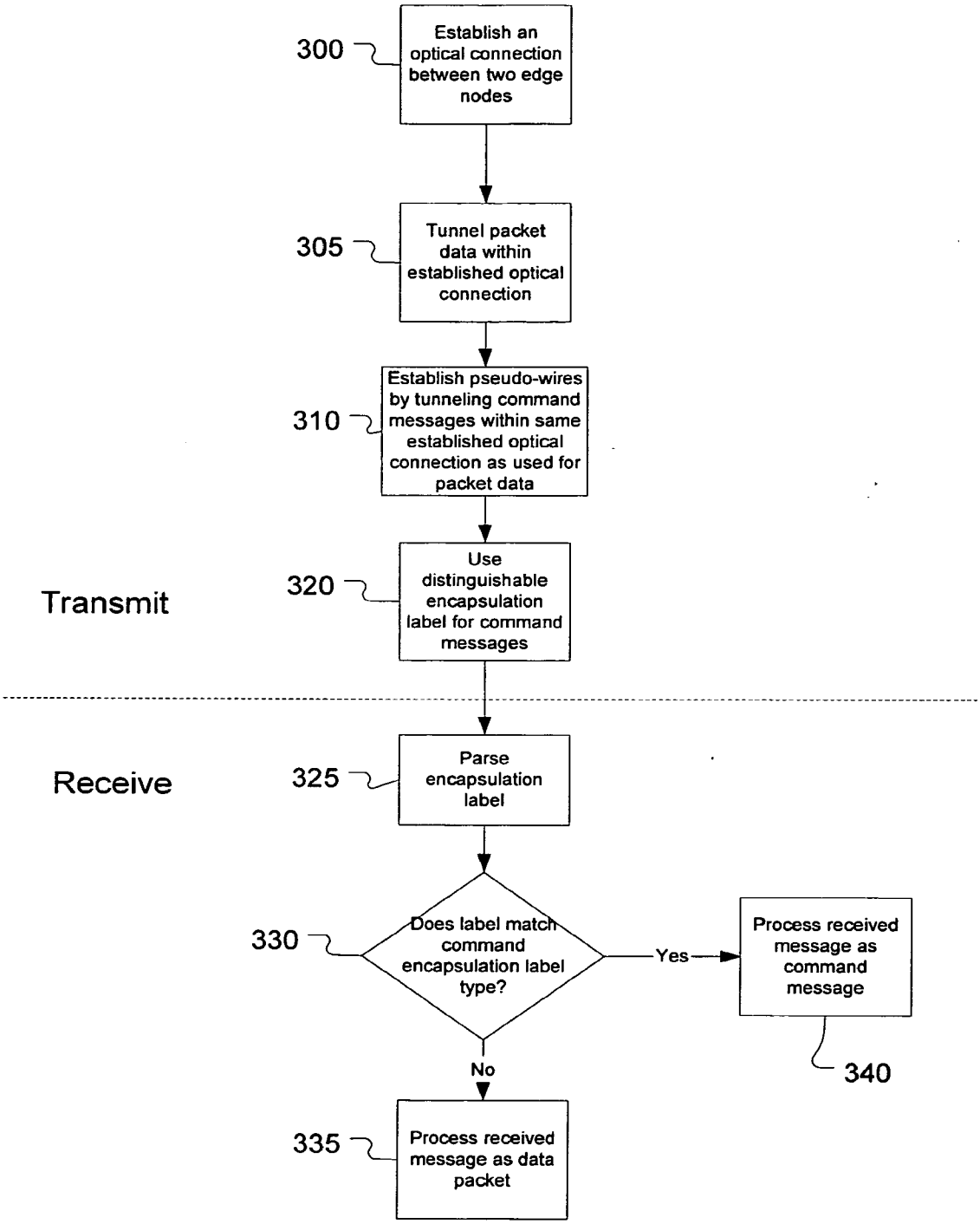

300
Establish an optical connection between two edge nodes
305
Tunnel packet data within established optical connection
310
Establish pseudo-wires by tunneling command messages within same established optical connection as used for packet data
320
Use distinguishable encapsulation label for command messages
Transmit
Receive
325
Parse encapsulation label
330
Does label match command encapsulation label type?
Yes
Process received message as command message
340
No
335
Process received message as data packet

Figure 14

Figure 15a

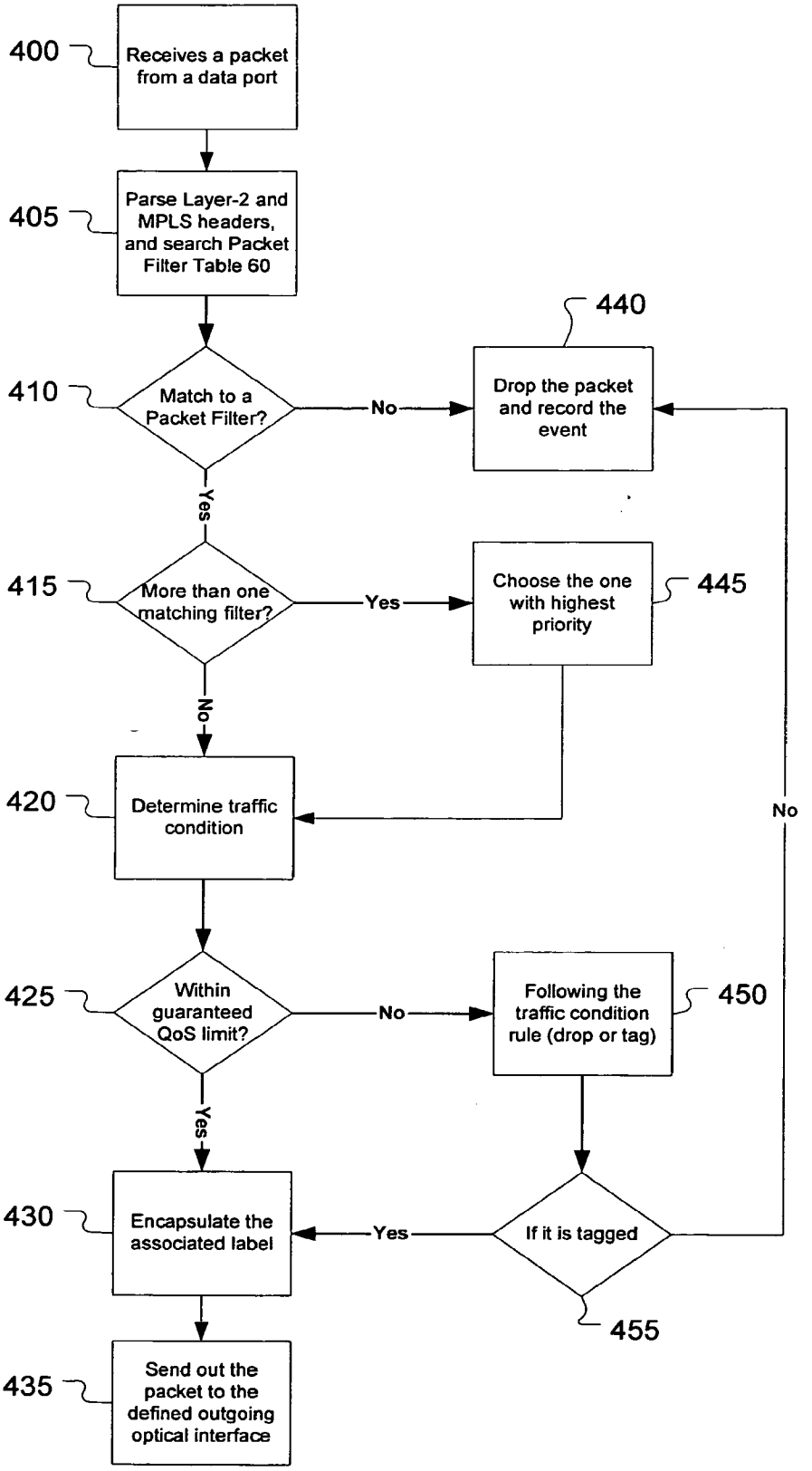

400
Receives a packet from a data port
405
Parse Layer-2 and MPLS headers, and search Packet Filter Table 60
410
Match to a Packet Filter?
No
440
Drop the packet and record the event
Yes
415
More than one matching filter?
Yes
Choose the one with highest priority
445
No
420
Determine traffic condition
425
Within guaranteed QoS limit?
No
Following the traffic condition rule (drop or tag)
450
Yes
430
Encapsulate the associated label
Yes
If it is tagged
No
455
435
Send out the packet to the defined outgoing optical interface

Figure 15b

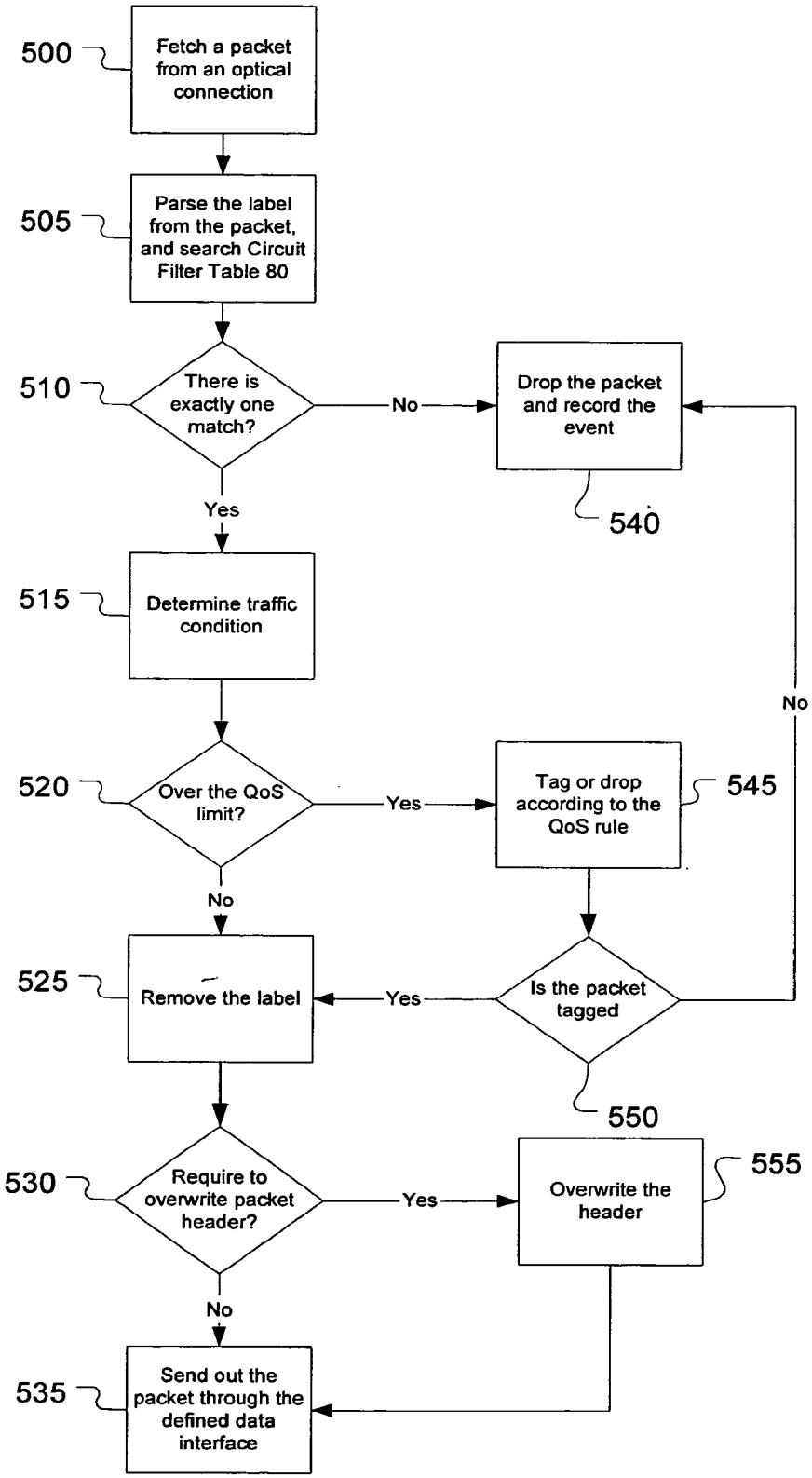
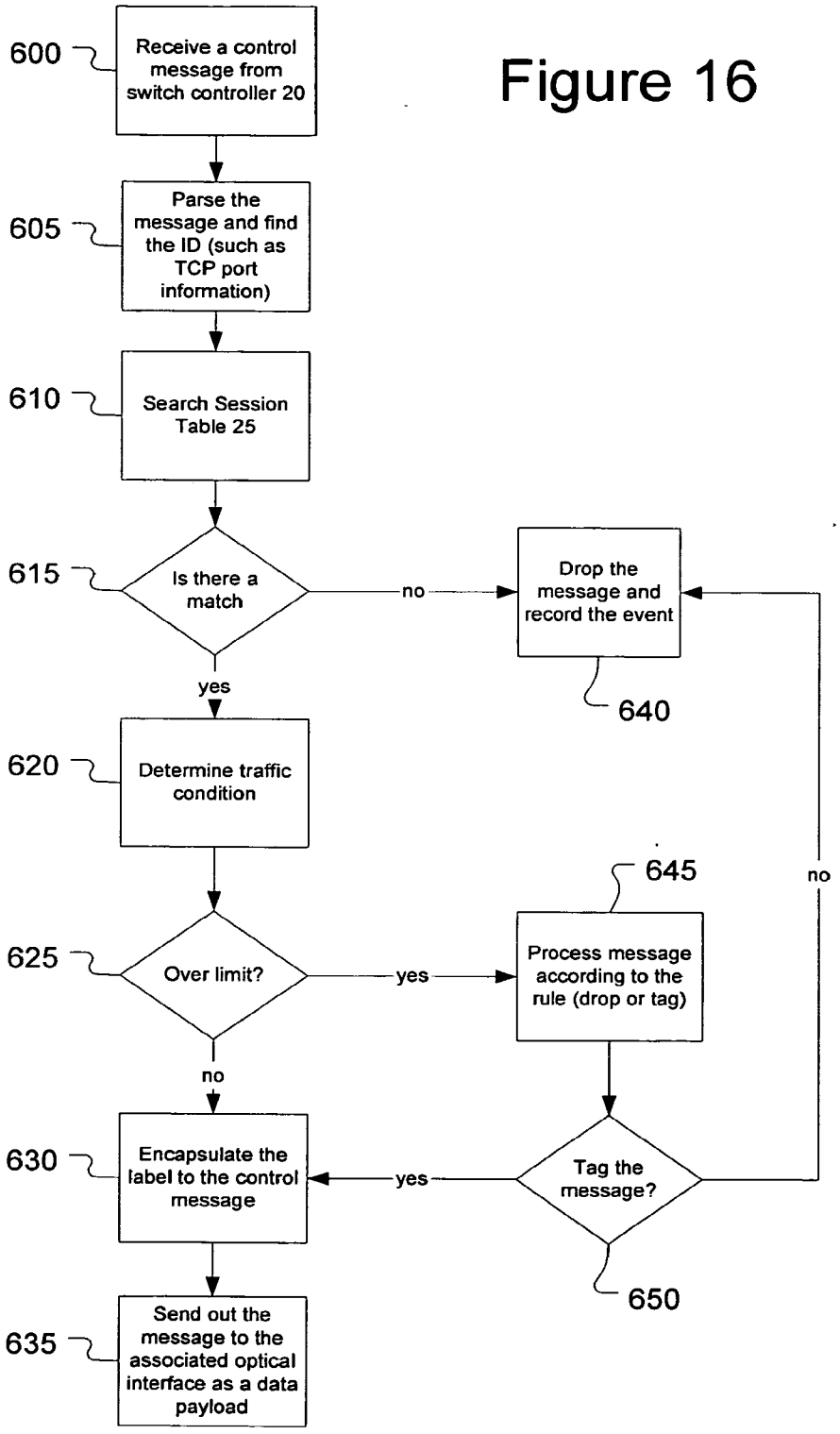

500
Fetch a packet from an optical connection
505
Parse the label from the packet, and search Circuit Filter Table 80
510
There is exactly one match?
No
Drop the packet and record the event
540
Yes
515
Determine traffic condition
520
Over the QoS limit?
Yes
Tag or drop according to the QoS rule
545
No
525
Remove the label
Yes
Is the packet tagged
No
550
530
Require to overwrite packet header?
Yes
Overwrite the header
555
No
535
Send out the packet through the defined data interface

Figure 16


600
Receive a control message from switch controller 20
605
Parse the message and find the ID (such as TCP port information)
610
Search Session Table 25
615
Is there a match
no
Drop the message and record the event
640
yes
620
Determine traffic condition
645
625
Over limit?
yes
Process message according to the rule (drop or tag)
no
630
Encapsulate the label to the control message
yes
Tag the message?
no
650
635
Send out the message to the associated optical interface as a data payload

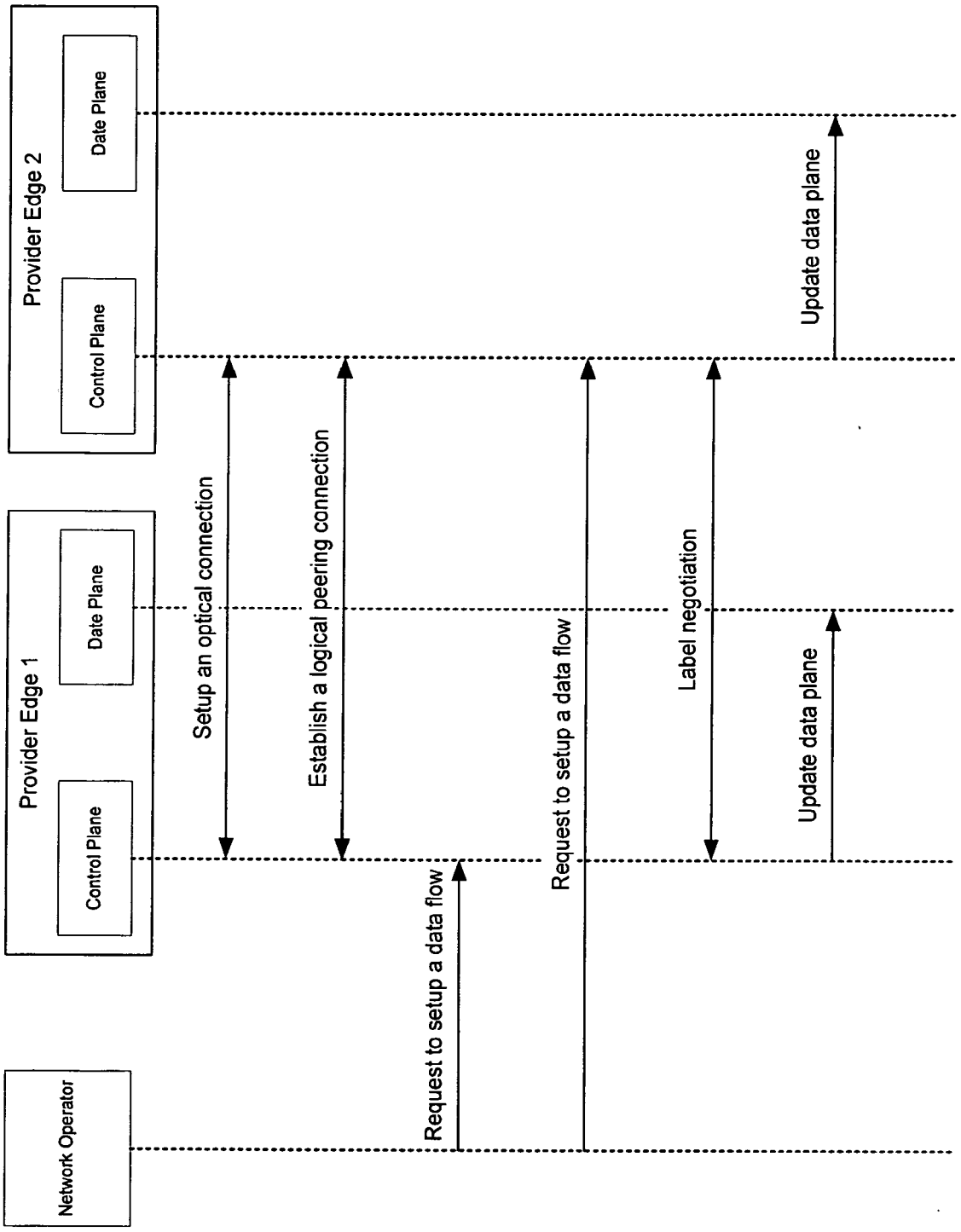

Network Operator
Provider Edge 1
Control Plane
Date Plane
Provider Edge 2
Control Plane
Date Plane
Request to setup a data flow
Setup an optical connection
Establish a logical peering connection
Request to setup a data flow
Label negotiation
Update data plane
Update data plane

Figure 17

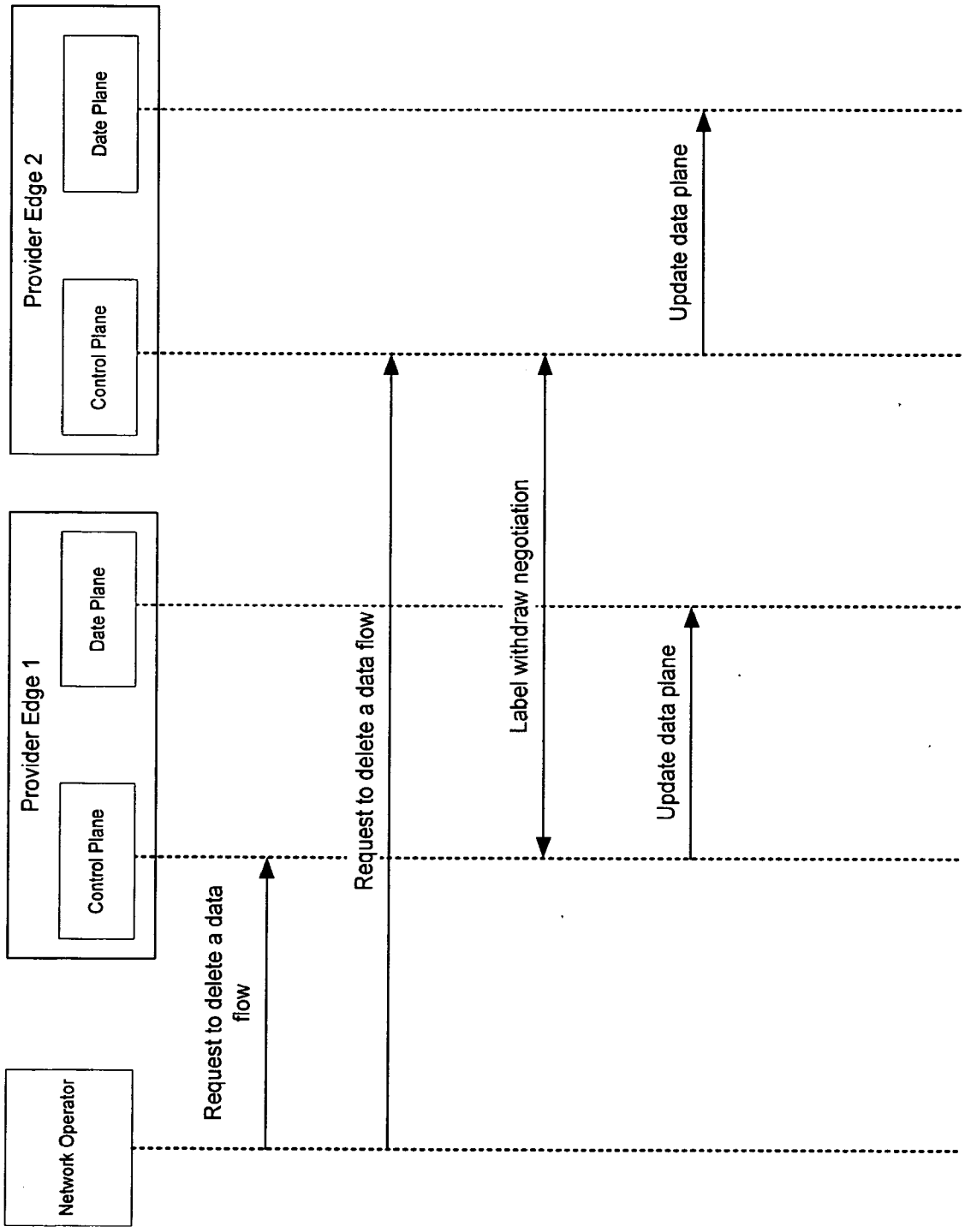

Network Operator
Provider Edge 1
Control Plane
Date Plane
Provider Edge 2
Control Plane
Date Plane
Request to delete a data flow
Request to delete a data flow
Label withdraw negotiation
Update data plane
Update data plane

Figure 18

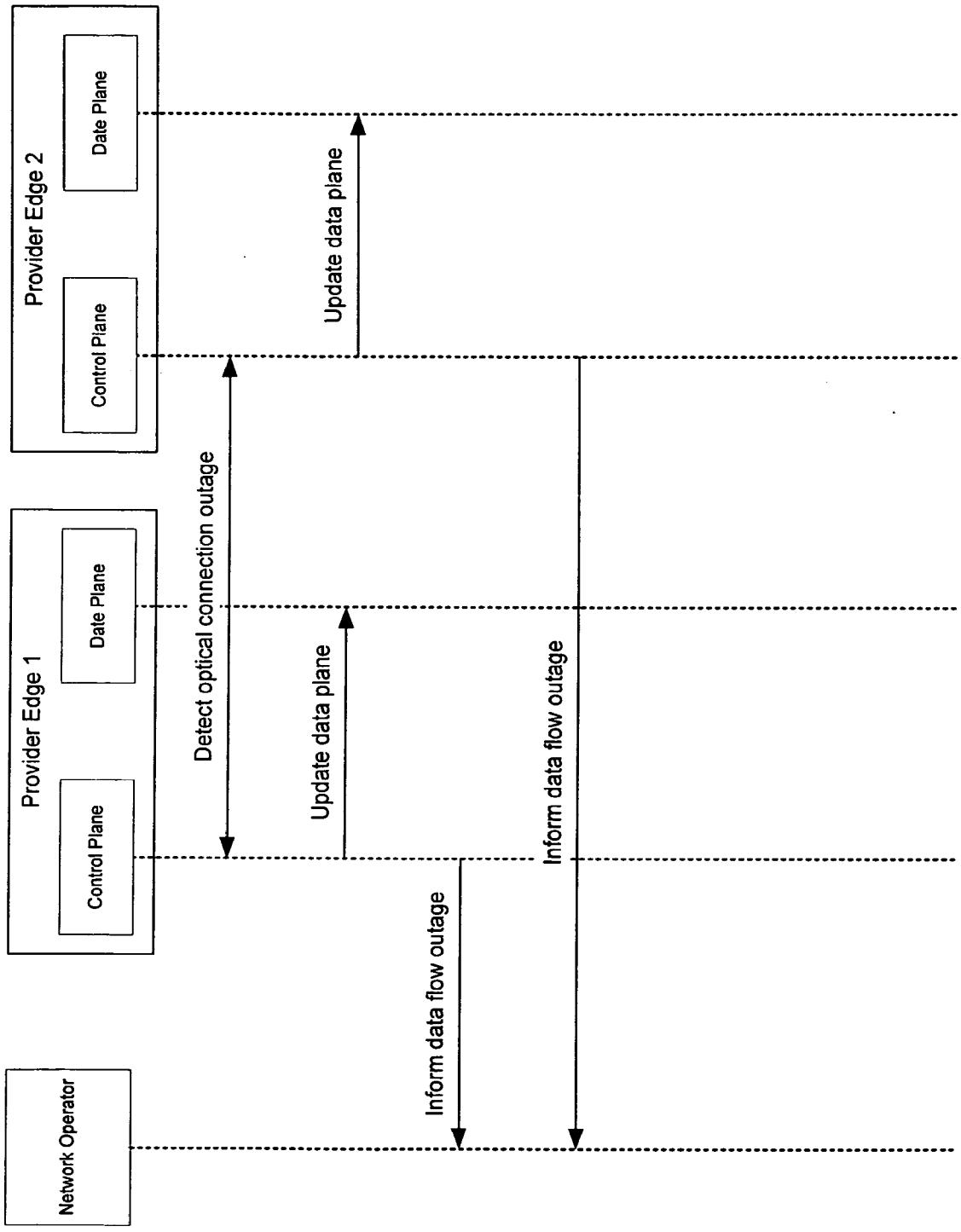

Provider Edge 2
Date Plane
Control Plane
Update data plane
Provider Edge 1
Date Plane
Control Plane
Detect optical connection outage
Update data plane
Inform data flow outage
Inform data flow outage
Network Operator

Figure 19

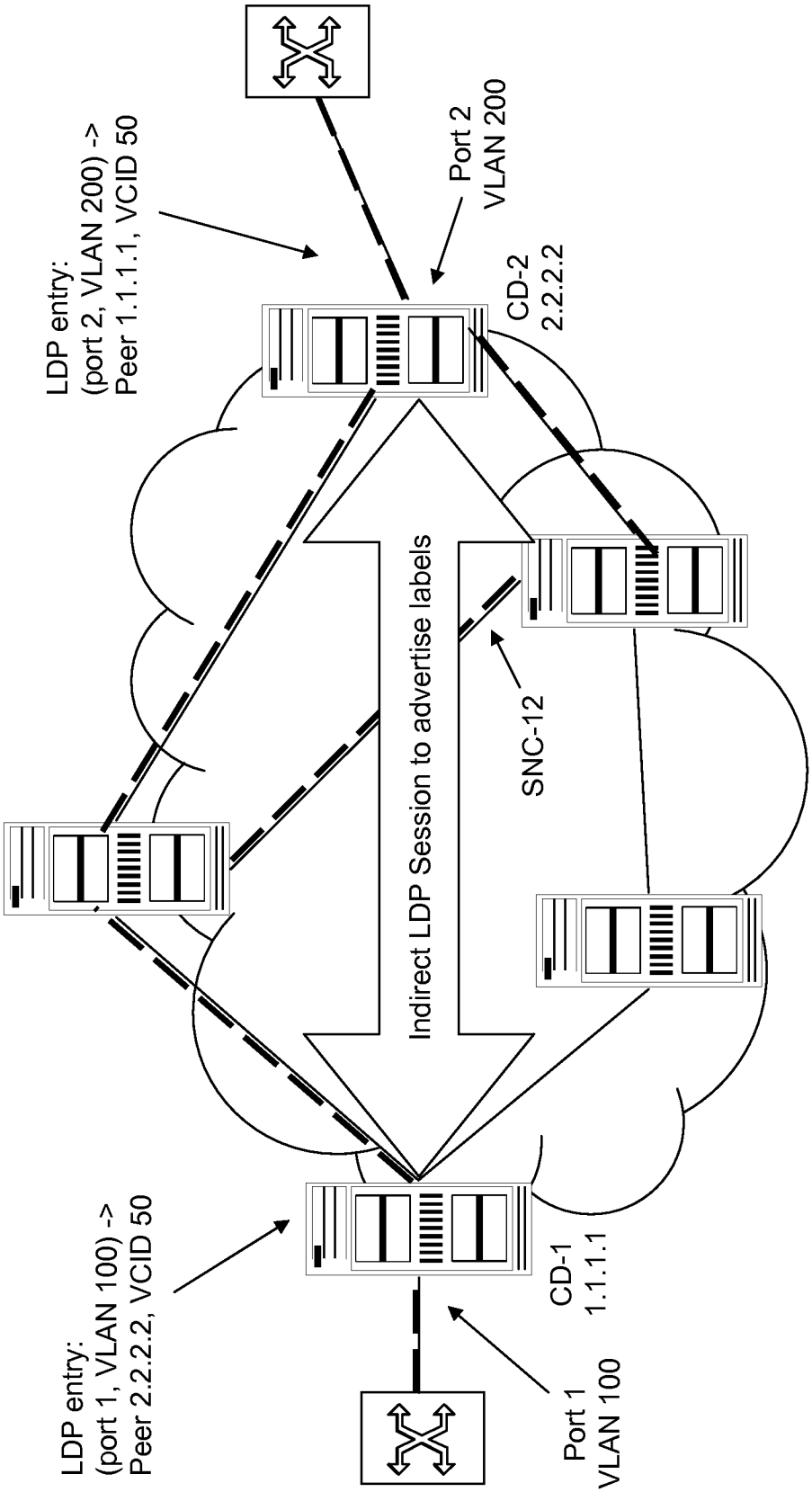

LDP entry:
(port 2, VLAN 200) ->
Peer 1.1.1.1, VCID 50
Port 2
VLAN 200
CD-2
2.2.2.2
Indirect LDP Session to advertise labels
SNC-12
LDP entry:
(port 1, VLAN 100) ->
Peer 2.2.2.2, VCID 50
CD-1
1.1.1.1
Port 1
VLAN 100
LDP advertises
Label 2000 for VCID 50
LDP advertises
Label 1000 for VCID 50
Tunnel data to 1.1.1.1, label 1000
1000
MAC Frame
Tunnel data to 2.2.2.2, label 2000
MAC Frame
2000

Figure 20

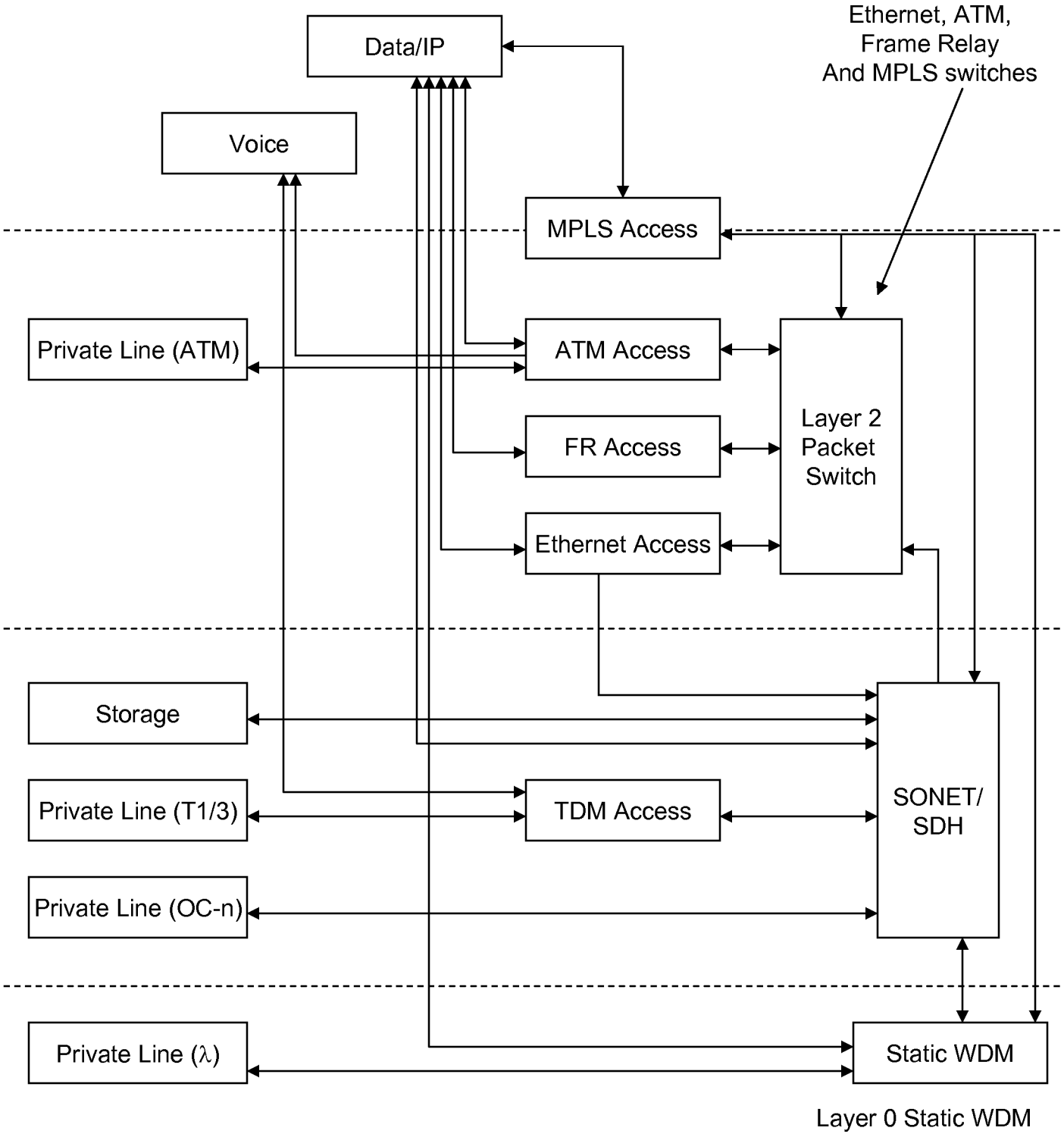


Figure 21
(Conventional)

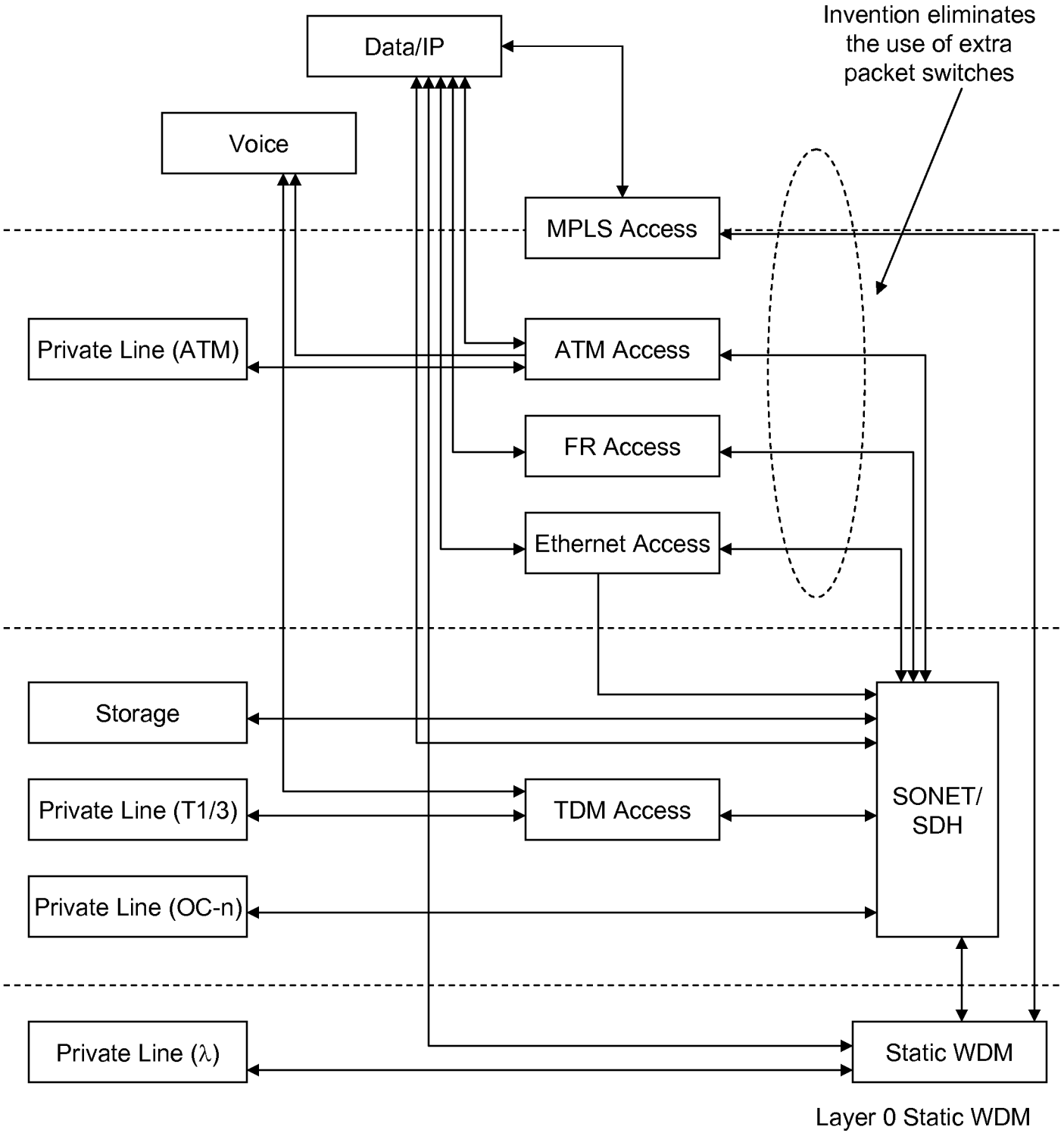

Invention eliminates the use of extra packet switches
Data/IP
Voice
MPLS Access
Private Line (ATM)
ATM Access
FR Access
Ethernet Access
Storage
Private Line (T1/3)
TDM Access
SONET/ SDH
Private Line (OC-n)
Private Line (λ)
Static WDM
Layer 0 Static WDM

Figure 22

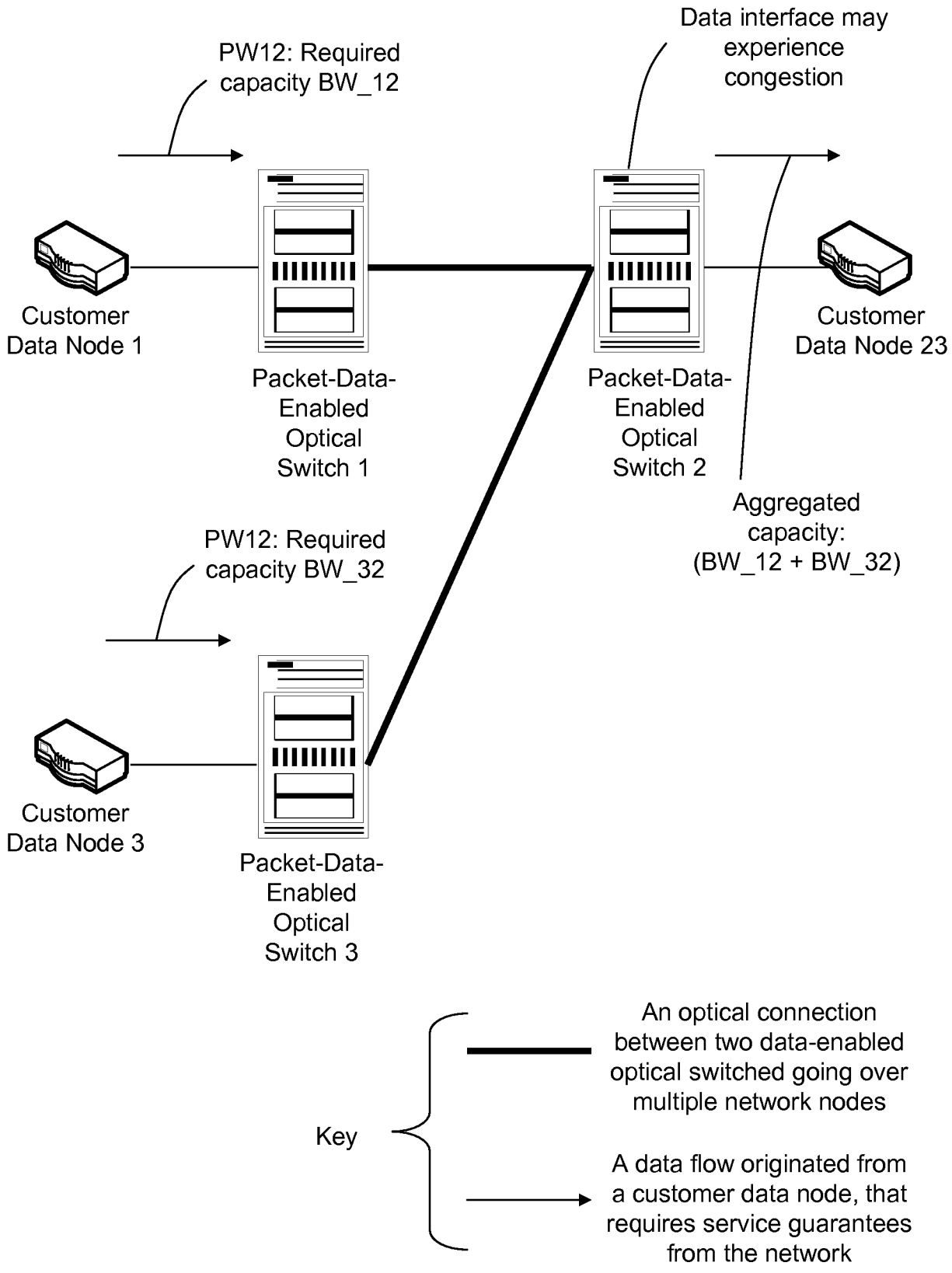

PW12: Required capacity BW_12
Data interface may experience congestion
Customer Data Node 1
Packet-Data-Enabled Optical Switch 1
Packet-Data-Enabled Optical Switch 2
Customer Data Node 23
Aggregated capacity: (BW_12 + BW_32)
PW12: Required capacity BW_32
Customer Data Node 3
Packet-Data-Enabled Optical Switch 3
Key
An optical connection between two data-enabled optical switched going over multiple network nodes
A data flow originated from a customer data node, that requires service guarantees from the network

Figure 23a

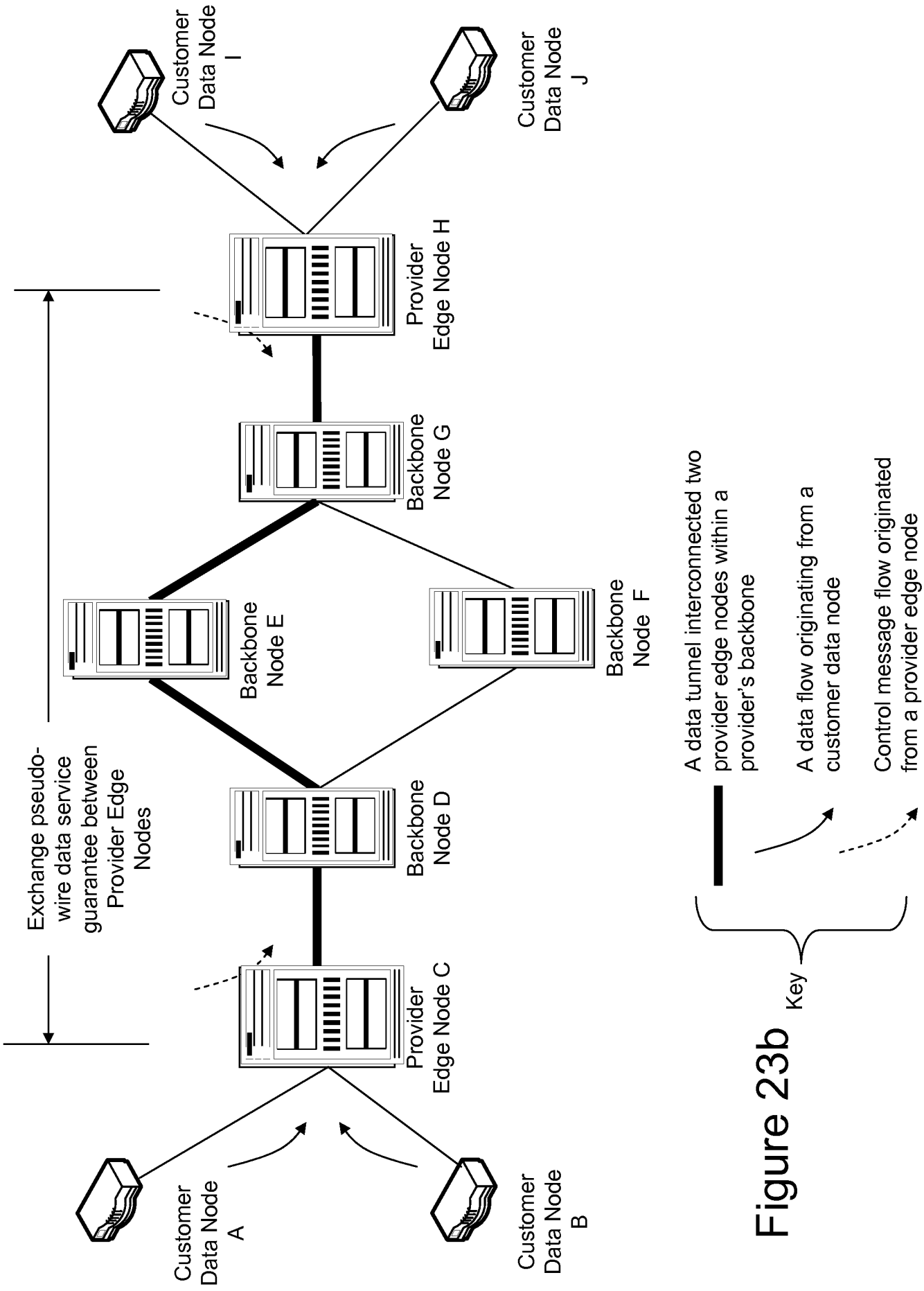

Customer Data Node I
Customer Data Node J
Provider Edge Node H
Backbone Node G
Backbone Node E
Backbone Node F
Backbone Node D
Provider Edge Node C
Exchange pseudo-wire data service guarantee between Provider Edge Nodes
Customer Data Node A
Customer Data Node B
A data tunnel interconnected two provider edge nodes within a provider's backbone
A data flow originating from a customer data node
Control message flow originated from a provider edge node
Key

Figure 23b

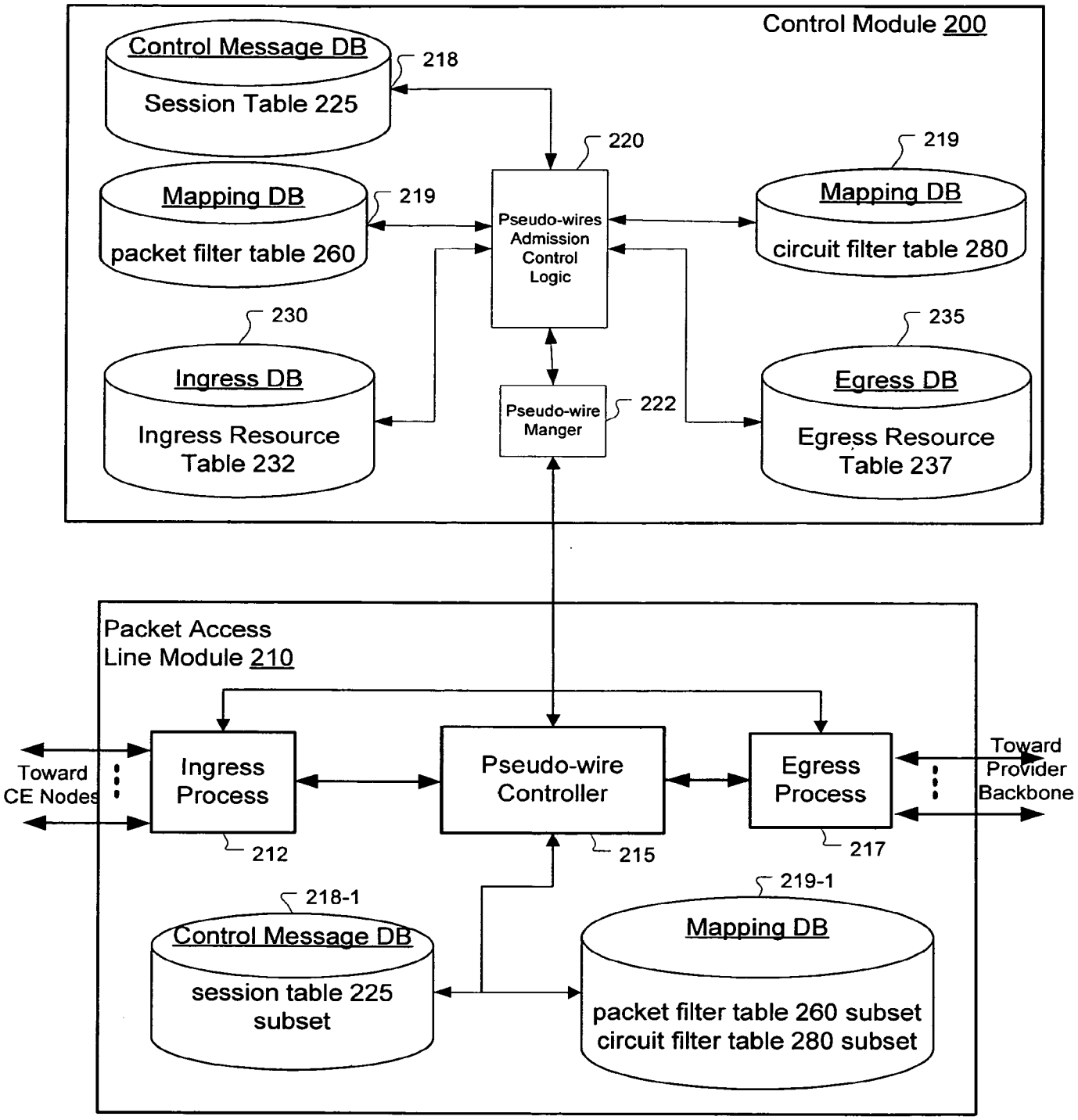

Control Module 200
Control Message DB
Session Table 225
218
220
219
Mapping DB
packet filter table 260
219
Pseudo-wires Admission Control Logic
Mapping DB
circuit filter table 280
230
235
Ingress DB
Ingress Resource Table 232
Pseudo-wire Manger
222
Egress DB
Egress Resource Table 237
Packet Access Line Module 210
Toward CE Nodes
Ingress Process
Pseudo-wire Controller
Egress Process
Toward Provider Backbone
212
215
217
218-1
219-1
Control Message DB
session table 225 subset
Mapping DB
packet filter table 260 subset
circuit filter table 280 subset

Figure 24

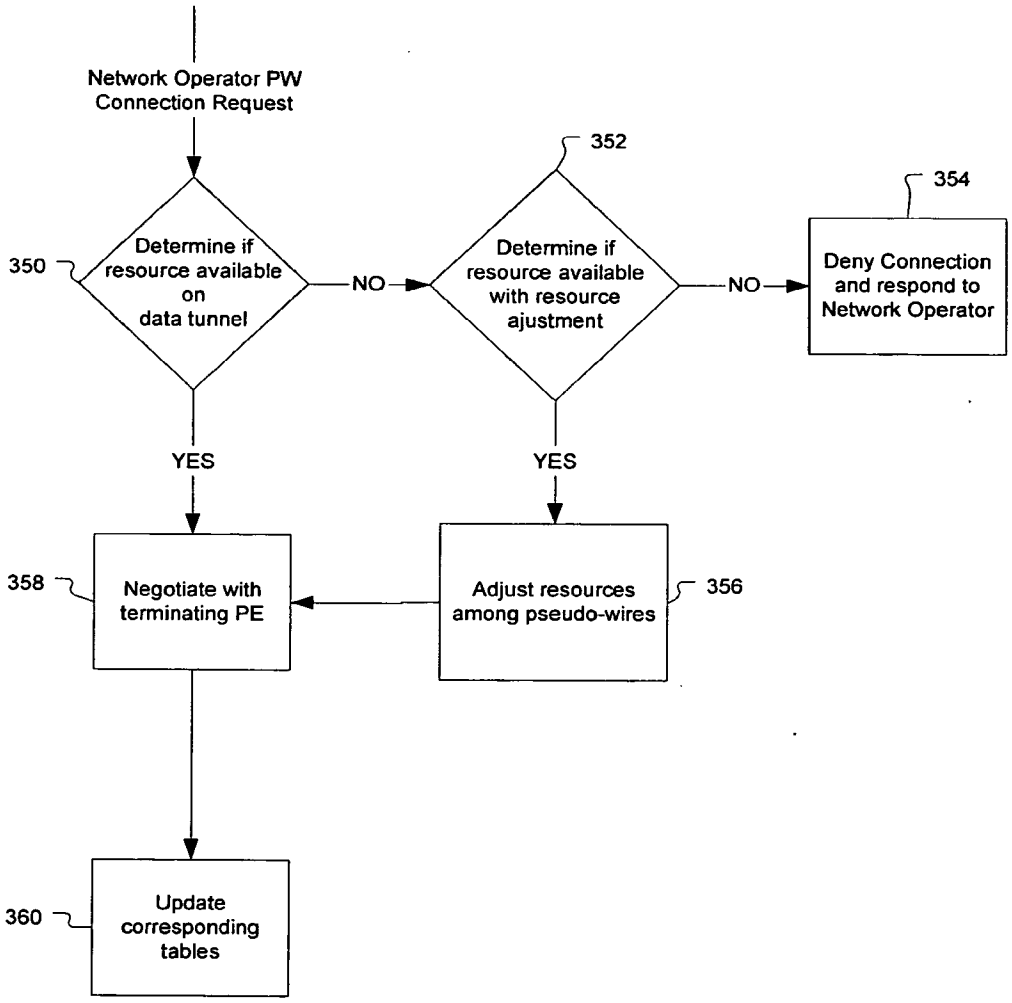

Network Operator PW Connection Request
350
Determine if resource available on data tunnel
NO
352
Determine if resource available with resource ajustment
NO
354
Deny Connection and respond to Network Operator
YES
YES
358
Negotiate with terminating PE
Adjust resources among pseudo-wires
356
360
Update corresponding tables

Figure 25a

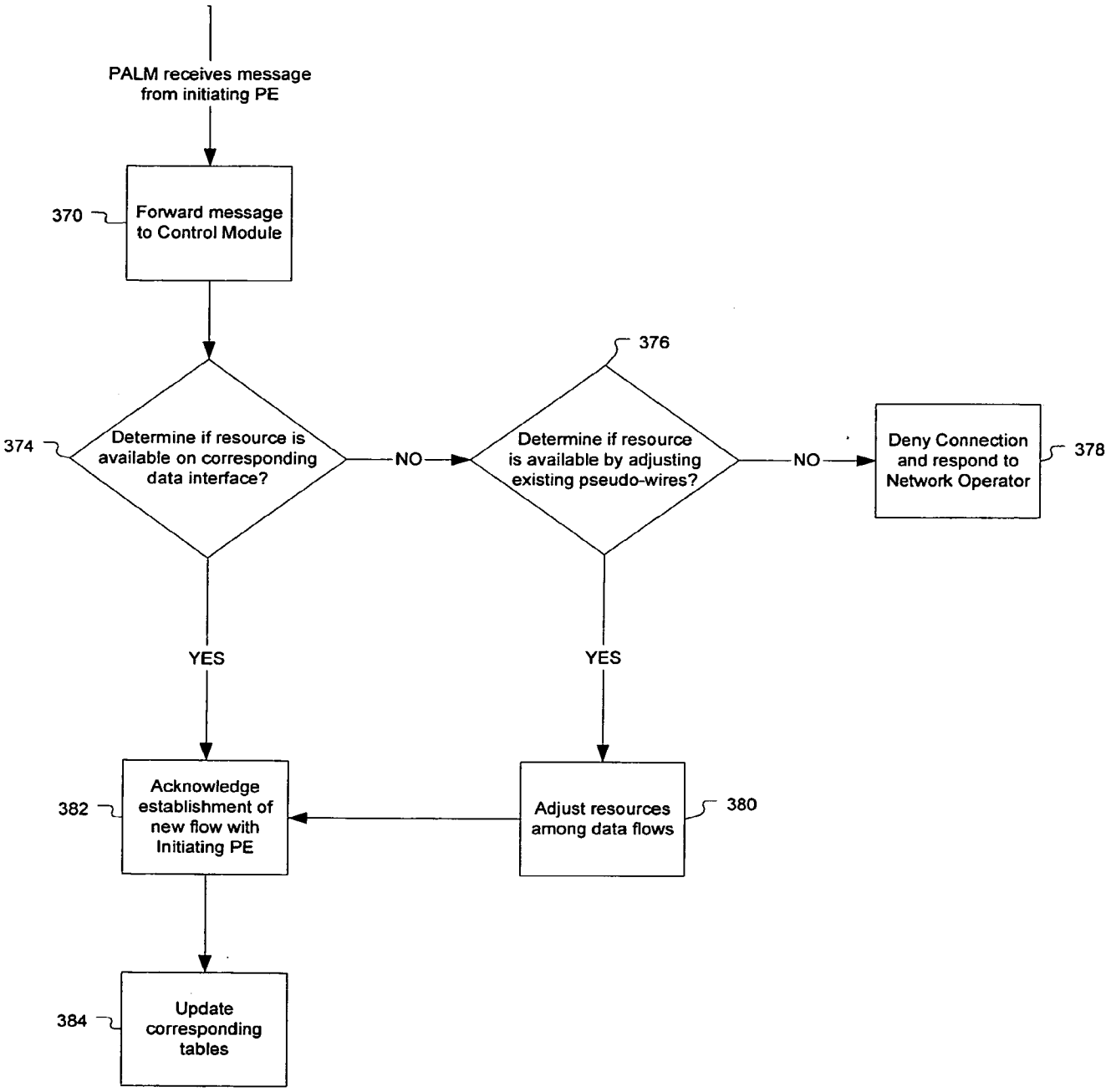

PALM receives message from initiating PE
370
Forward message to Control Module
374
Determine if resource is available on corresponding data interface?
NO
376
Determine if resource is available by adjusting existing pseudo-wires?
NO
Deny Connection and respond to Network Operator
378
YES
YES
382
Acknowledge establishment of new flow with Initiating PE
Adjust resources among data flows
380
384
Update corresponding tables

Figure 25b

REPLACEMENT SHEET

260

PACKET FILTER TABLE						
PACKET FILTER (DATA INTERFACE, LABEL)	DATA TUNNEL	ENCAPSULATION LABEL	CIR	CLASS	SETUP PRIORITY	HOLDING PRIORITY
PACKET FILTER-1 (PORT 1, ETHERNET VLAN 100)	SONET VCG NUMBER 3	MPLS LABEL 10000	50 Mb/Sec	AF-1	3	5
PACKET FILTER-2 (PORT 5, ATM VCI/VPI 12/45)	ROUTER INTERFACE 5	MPLS LABEL 20000	8 Mb/Sec	EF	3	5
PACKET FILTER-3 (PORT 2, FR DLCI 900)	SONET VCG NUMBER 3	MPLS LABEL 500	10 Mb/Sec	AF-1	3	5
PACKET FILTER-4 (PORT 10)	ETHERNET INTERFACE 12	MPLS LABEL 50001	1 Gb/Sec	AF-3	5	5

Figure 26

REPLACEMENT SHEET

280

CIRCUIT FILTER TABLE					
CIRCUIT FILTER (DATA TUNNEL, LABEL)	OUTGOING DATA INTERFACE	CIR	CLASS	SETUP PRIORITY	HOLDING PRIORITY
CIRCUIT FILTER-1 (SONET VCG 3, LABEL 20000)	DATA PORT 1	50 Mb/Sec	AF-1	3	3
CIRCUIT FILTER-2 (SONET VCG 3, LABEL 20001)	DATA PORT 2	8 Mb/Sec	EF	3	3
CIRCUIT FILTER-3 (OPTICAL INTERFACE 1, LABEL 300)	DATA PORT 10	10 Gb/Sec	AF-3	3	3
CIRCUIT FILTER-4 (SONET VCG 5, LABEL 12000)	DATA PORT 1	100 Mb/Sec	AF-1	1	1
CIRCUIT FILTER-5 (SONET VCG 3, LABEL 3)	DATA PORT 2	1 Gb/Sec	AF-1	5	5

Figure 27

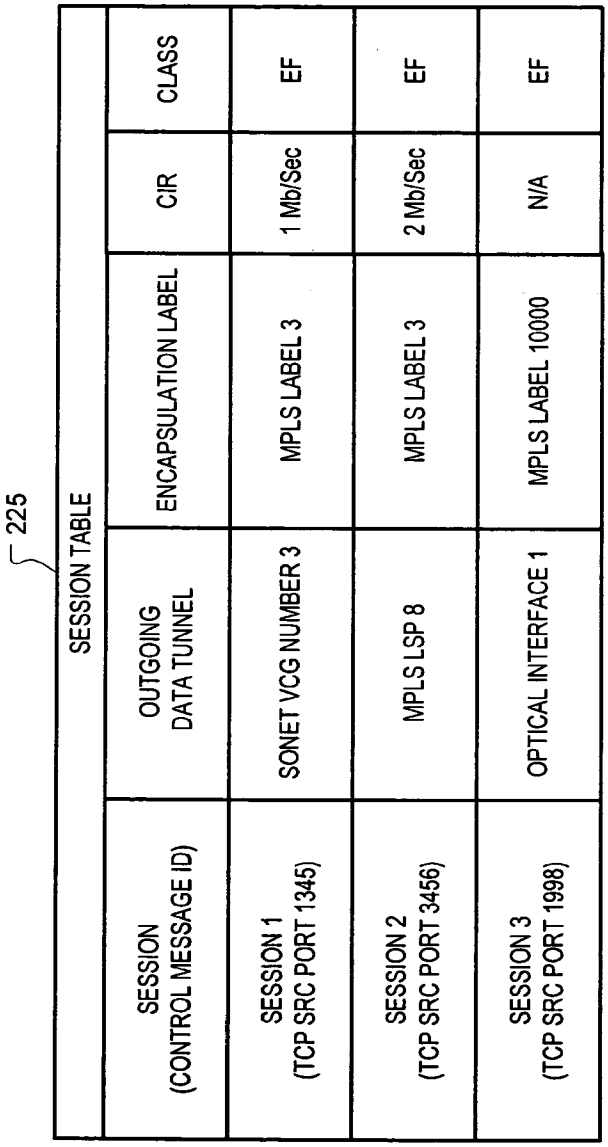

225
SESSION TABLE
SESSION (CONTROL MESSAGE ID)
OUTGOING DATA TUNNEL
ENCAPSULATION LABEL
CIR
CLASS
SESSION 1 (TCP SRC PORT 1345)
SONET VCG NUMBER 3
MPLS LABEL 3
1 Mb/Sec
EF
SESSION 2 (TCP SRC PORT 3456)
MPLS LSP 8
MPLS LABEL 3
2 Mb/Sec
EF
SESSION 3 (TCP SRC PORT 1998)
OPTICAL INTERFACE 1
MPLS LABEL 10000
N/A
EF

Figure 28

REPLACEMENT SHEET

232

INGRESS RESOURCE TABLE					
DATA TUNNEL	PHYSICAL BANDWIDTH	AVAILABLE TOTAL BANDWIDTH	AVAILABLE BANDWIDTH CLASS 1	AVAILABLE BANDWIDTH CLASS ...	AVAILABLE BANDWIDTH CLASS N
MPLS LSP with label 45	80 Mb/Sec	70 Mb/Sec	20 Mb/sec	...	30 Mb/sec
SONET VCG 4	100 Mb/Sec	50 Mb/Sec	50 Mb/Sec	...	0
DEDICATED POS CONNECTION	45 Mb/Sec	12 Mb/Sec	1.5 Mb/src	...	3.0 Mb/src

Figure 29a

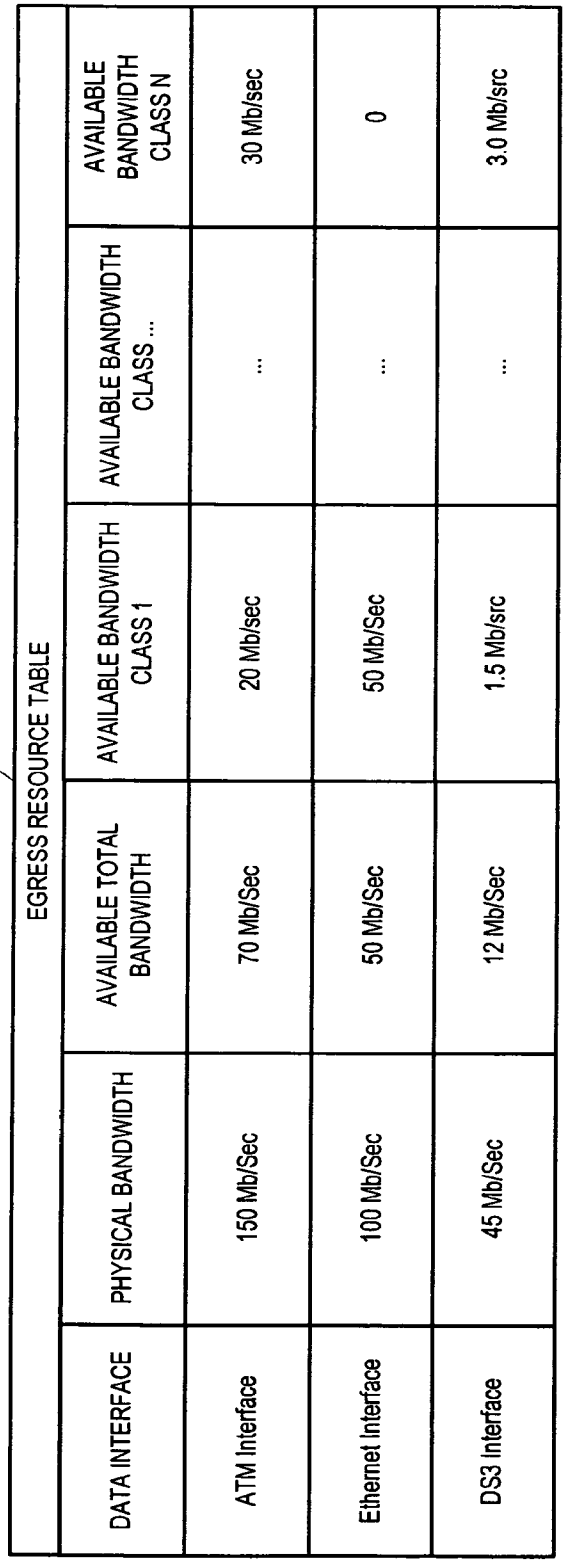
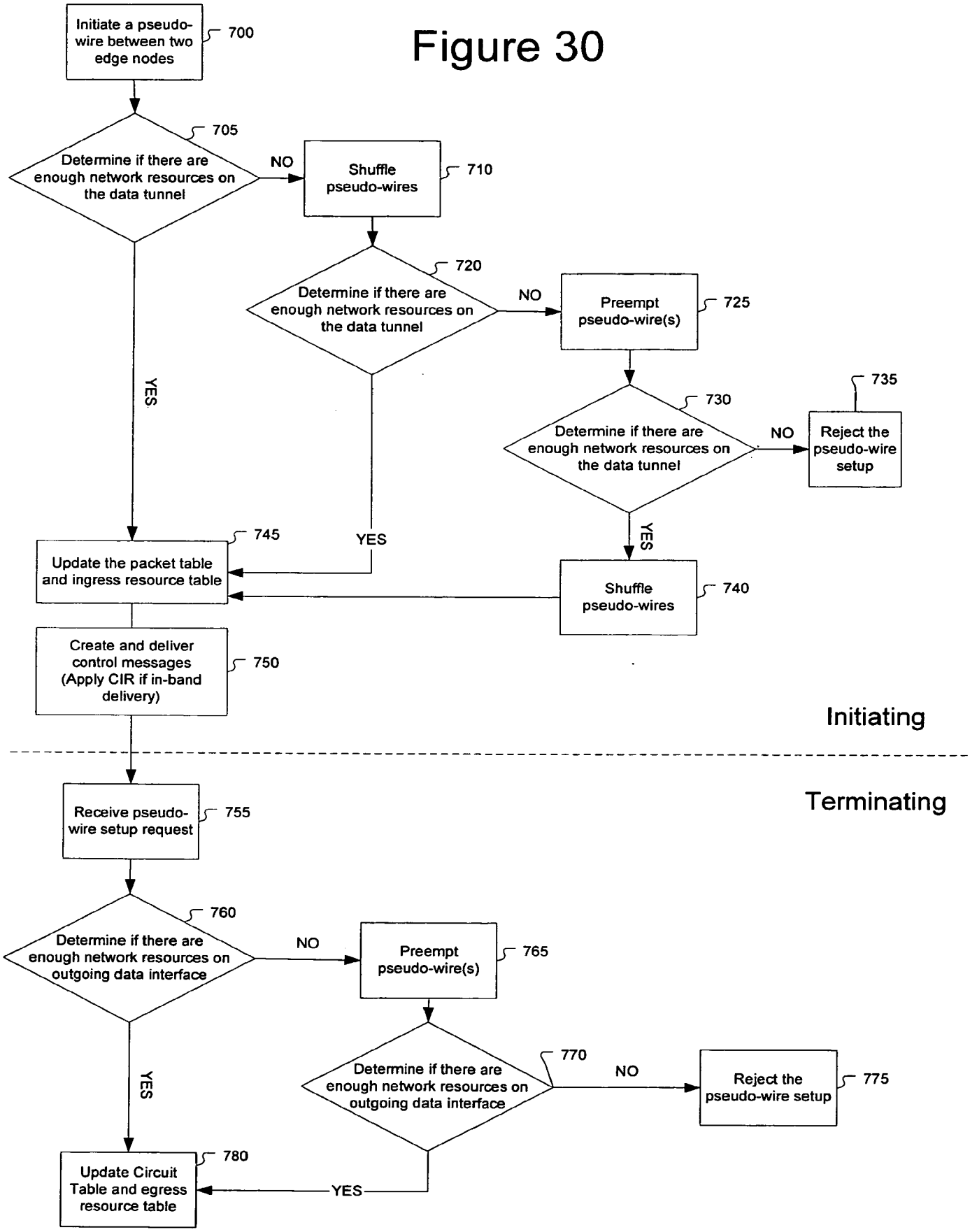

237
EGRESS RESOURCE TABLE
DATA INTERFACE
PHYSICAL BANDWIDTH
AVAILABLE TOTAL BANDWIDTH
AVAILABLE BANDWIDTH CLASS 1
AVAILABLE BANDWIDTH CLASS ...
AVAILABLE BANDWIDTH CLASS N
ATM Interface
150 Mb/Sec
70 Mb/Sec
20 Mb/sec
...
30 Mb/sec
Ethernet Interface
100 Mb/Sec
50 Mb/Sec
50 Mb/Sec
...
0
DS3 Interface
45 Mb/Sec
12 Mb/Sec
1.5 Mb/src
...
3.0 Mb/src

Figure 29b

Figure 30


Initiate a pseudo-wire between two edge nodes
700
Determine if there are enough network resources on the data tunnel
705
NO
Shuffle pseudo-wires
710
YES
Determine if there are enough network resources on the data tunnel
720
NO
Preempt pseudo-wire(s)
725
Determine if there are enough network resources on the data tunnel
730
NO
Reject the pseudo-wire setup
735
YES
YES
Update the packet table and ingress resource table
745
Shuffle pseudo-wires
740
Create and deliver control messages (Apply CIR if in-band delivery)
750
Initiating
Terminating
Receive pseudo-wire setup request
755
Determine if there are enough network resources on outgoing data interface
760
NO
Preempt pseudo-wire(s)
765
YES
Determine if there are enough network resources on outgoing data interface
770
NO
Reject the pseudo-wire setup
775
Update Circuit Table and egress resource table
780
YES

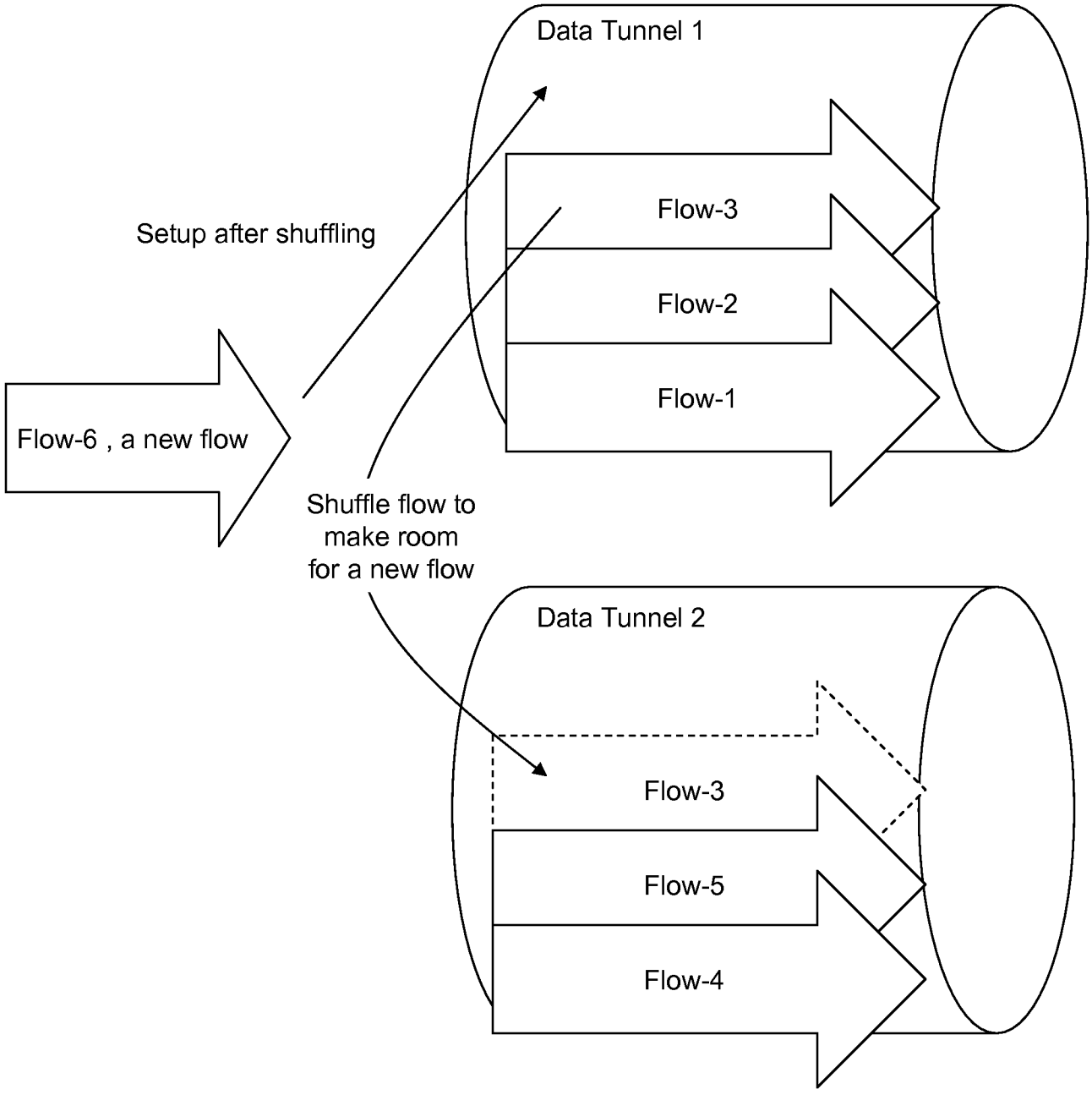

Data Tunnel 1
Flow-3
Flow-2
Flow-1
Setup after shuffling
Flow-6 , a new flow
Shuffle flow to
make room
for a new flow
Data Tunnel 2
Flow-3
Flow-5
Flow-4

Figure 31

Figure 32

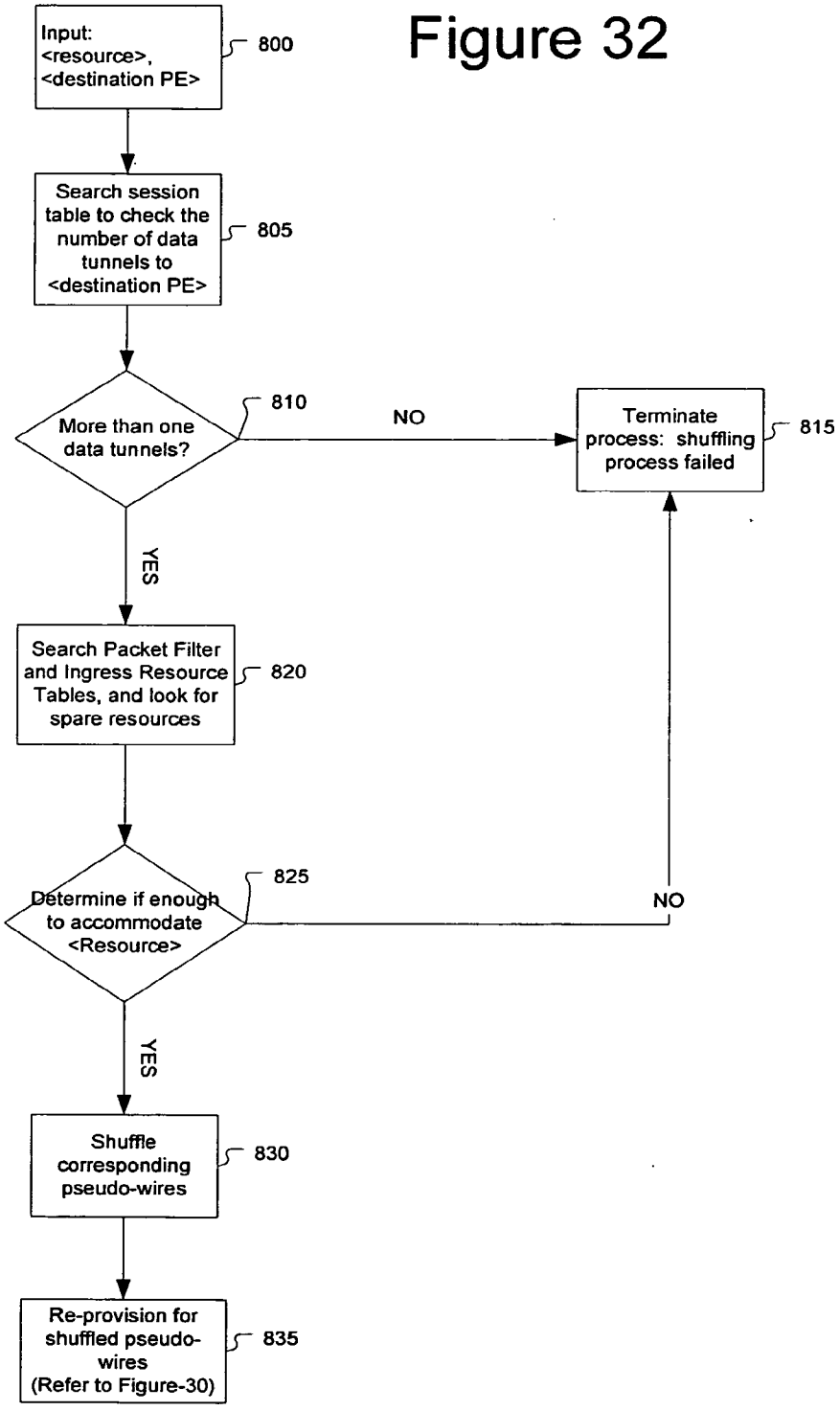
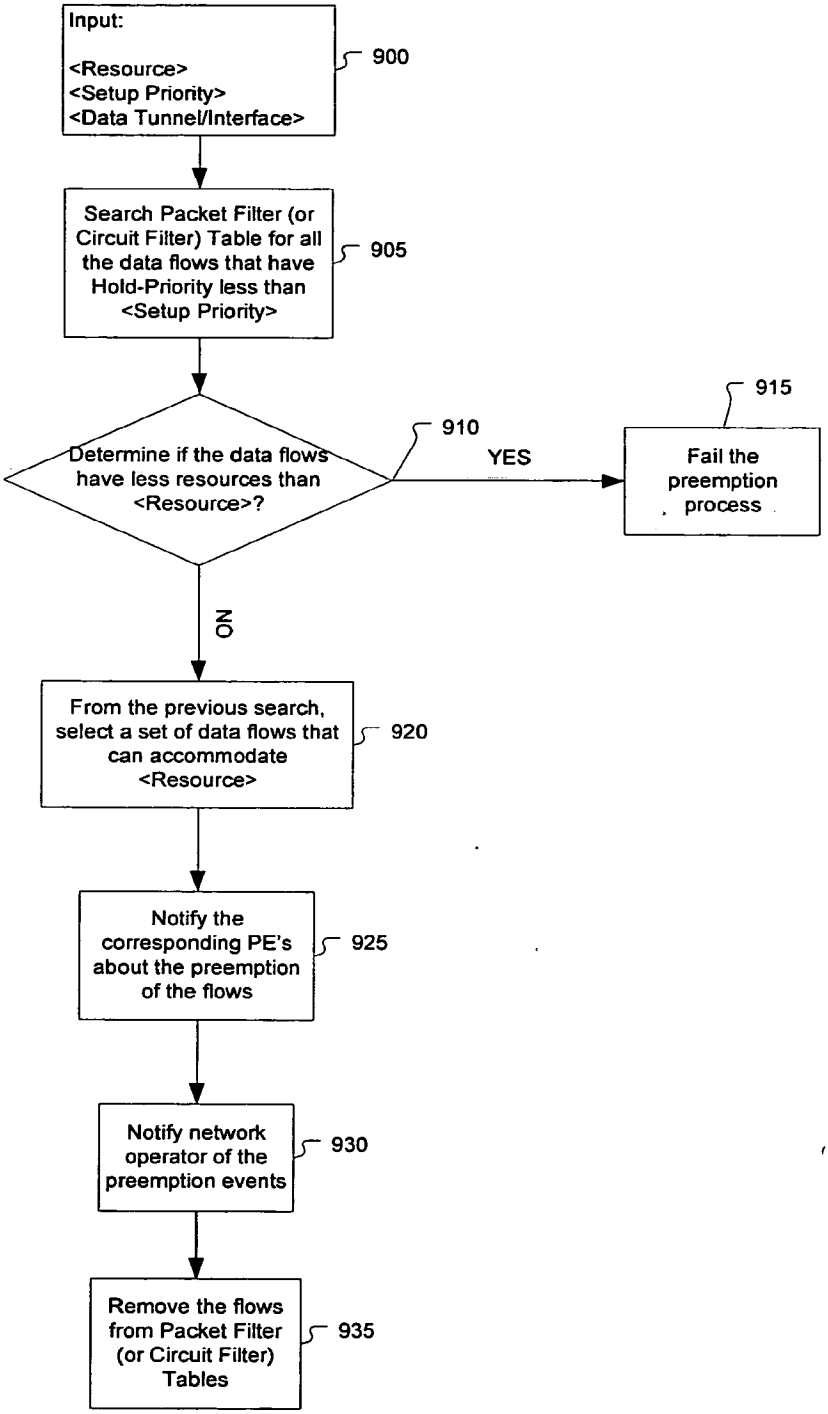

Input: <resource>, <destination PE>
800
Search session table to check the number of data tunnels to <destination PE>
805
More than one data tunnels?
810
NO
Terminate process: shuffling process failed
815
YES
Search Packet Filter and Ingress Resource Tables, and look for spare resources
820
Determine if enough to accommodate <Resource>
825
NO
YES
Shuffle corresponding pseudo-wires
830
Re-provision for shuffled pseudo-wires (Refer to Figure-30)
835

Figure 33


Input:
<Resource>
<Setup Priority>
<Data Tunnel/Interface>
900
Search Packet Filter (or Circuit Filter) Table for all the data flows that have Hold-Priority less than <Setup Priority>
905
Determine if the data flows have less resources than <Resource>?
910
YES
915
Fail the preemption process
NO
From the previous search, select a set of data flows that can accommodate <Resource>
920
Notify the corresponding PE's about the preemption of the flows
925
Notify network operator of the preemption events
930
Remove the flows from Packet Filter (or Circuit Filter) Tables
935

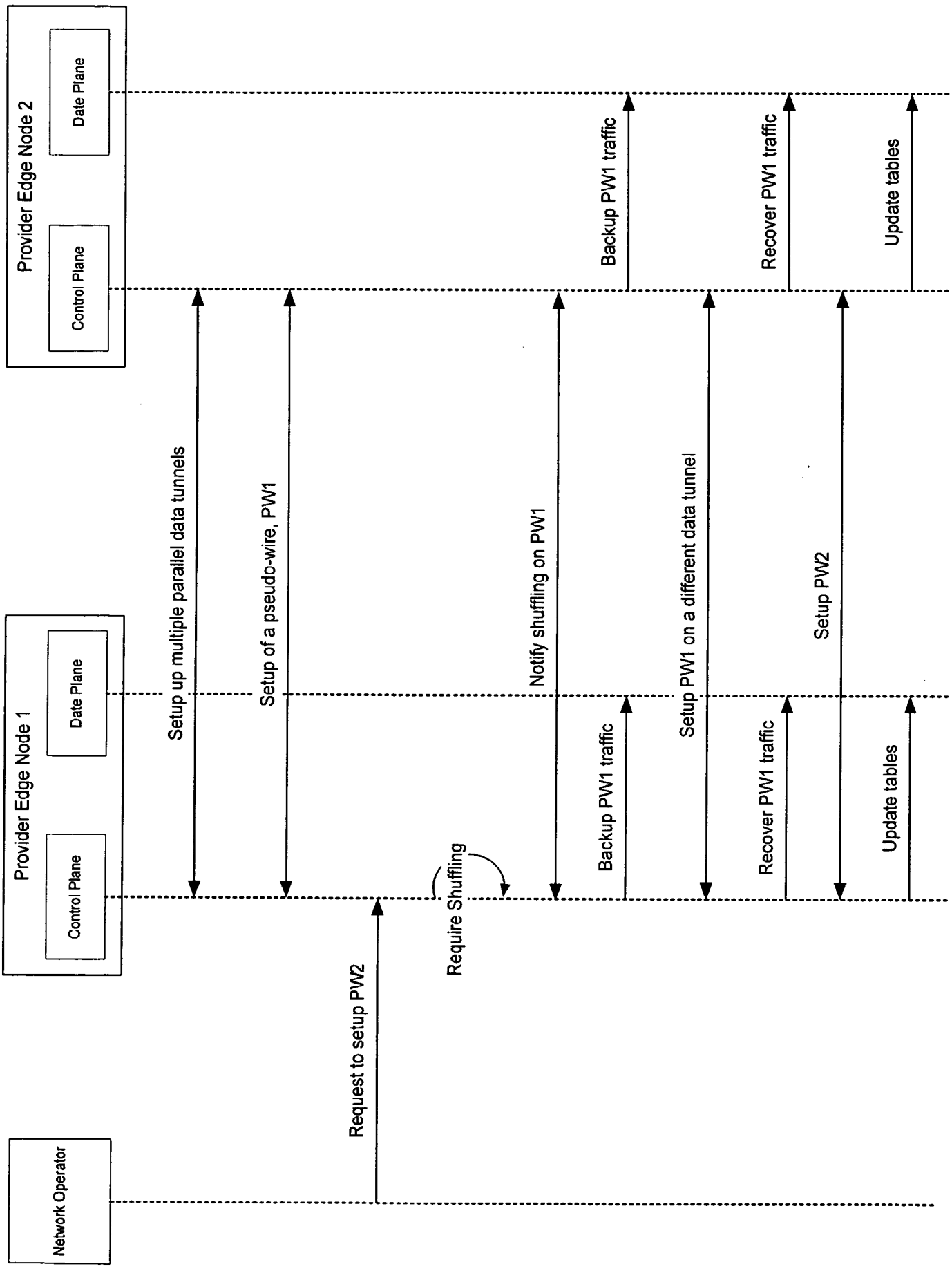

Provider Edge Node 2
Control Plane
Date Plane
Provider Edge Node 1
Control Plane
Date Plane
Network Operator
Setup up multiple parallel data tunnels
Setup of a pseudo-wire, PW1
Request to setup PW2
Require Shuffling
Notify shuffling on PW1
Backup PW1 traffic
Setup PW1 on a different data tunnel
Recover PW1 traffic
Update tables
Backup PW1 traffic
Recover PW1 traffic
Setup PW2
Update tables

Figure 34

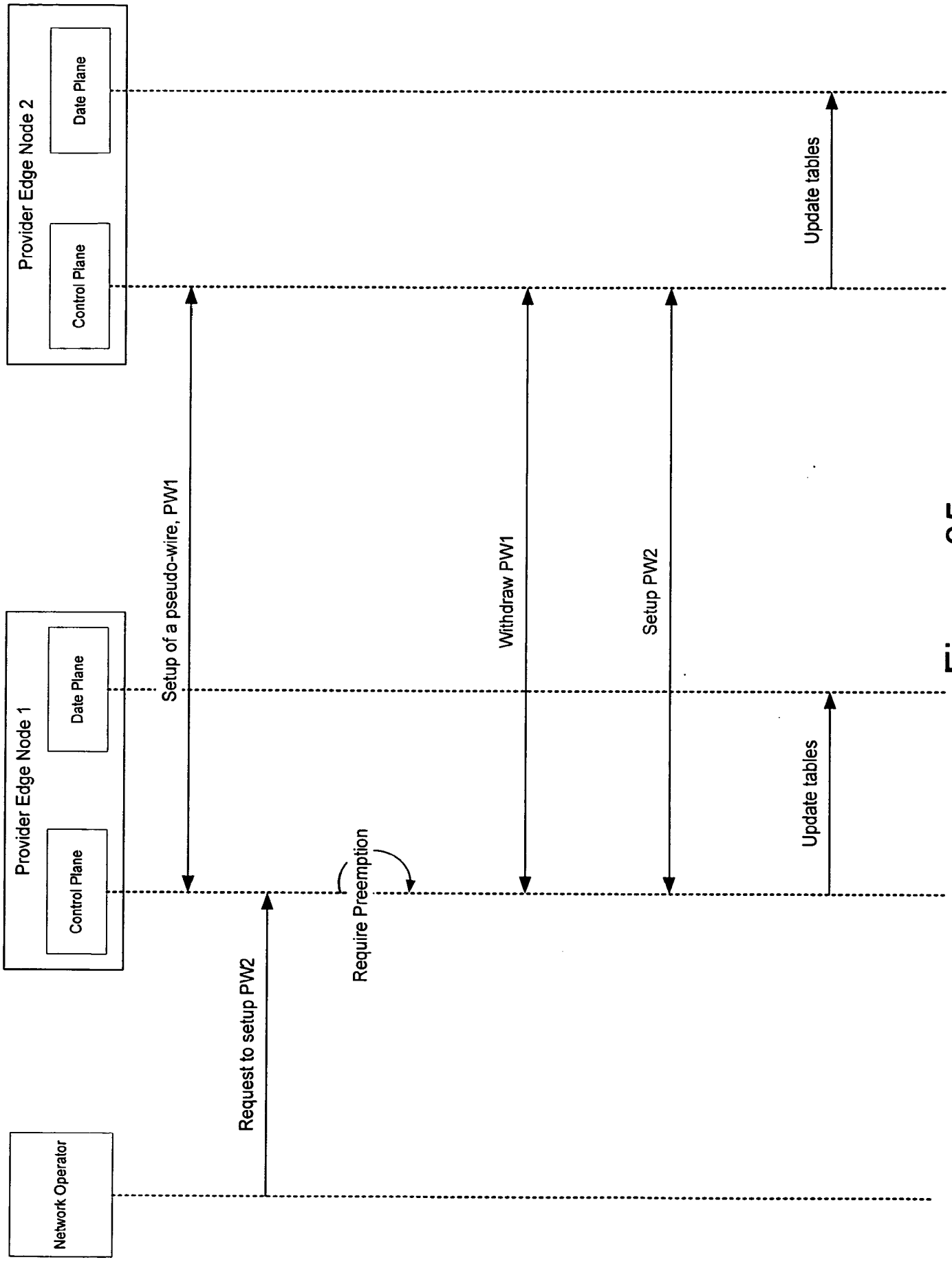

Provider Edge Node 2
Control Plane
Date Plane
Provider Edge Node 1
Control Plane
Date Plane
Network Operator
Setup of a pseudo-wire, PW1
Withdraw PW1
Setup PW2
Update tables
Update tables
Request to setup PW2
Require Preemption

Figure 35

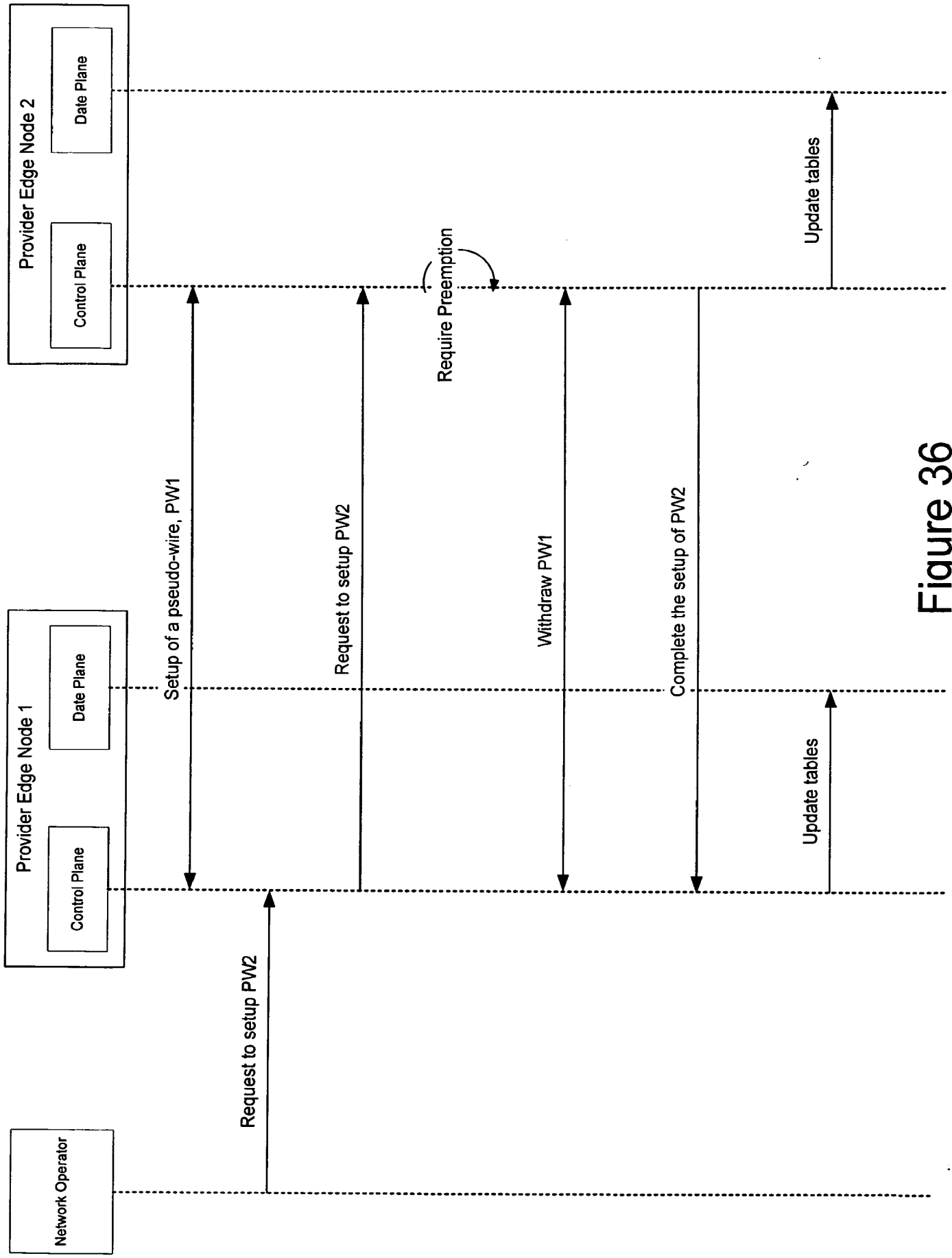

Provider Edge Node 2
Control Plane
Date Plane
Provider Edge Node 1
Control Plane
Date Plane
Network Operator
Setup of a pseudo-wire, PW1
Request to setup PW2
Require Preemption
Withdraw PW1
Complete the setup of PW2
Update tables
Request to setup PW2
Update tables

Figure 36